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MUNICIPAL SEWAGE TREATMENT WITH A ROTATING BIOLOGICAL CONTACTOR

ALLIS-CHALMERS

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MUNICIPAL SEWAGE TREATMENT
WITH A
ROTATING BIOLOGICAL CONTACTOR

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
DEPARTMENT OF THE INTERIOR

BY

ALLIS-CHALMERS
RESEARCH DIVISION
MILWAUKEE, WISCONSIN

CONTRACT NO. 14-12-24 - MODIFICATION NO. 2

MAY, 1969

FWPCA REVIEW NOTICE

This report has been reviewed by the Federal Water Pollution Control Administration and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Water Pollution Control Administration.

ABSTRACT

A Rotating Biological Contactor (RBC) was installed at the Milwaukee Metropolitan Sewerage Commission treatment plant at Jones Island to demonstrate the feasibility of treating municipal waste with an RBC system.

The RBC system effectively treated domestic sewage at high loading rates. Ninety percent COD removal was attained at a loading of 350 to 400 pounds of COD per day per thousand cubic feet of disc volume. Pounds of COD removed increased with pounds of COD applied. Efficiency of treatment improved with increased retention time. Percent BOD removal was approximately five percent greater than percent COD removal. Lower disc speed resulted in a slightly lower efficiency. Lower strength wastes are not as efficiently treated as higher strength wastes at the same organic loading. Recovery from high hydraulic loading is rapid.

This report was submitted in fulfillment of Contract 14-12-24 Modification 2 between the Federal Water Pollution Control Administration and Allis-Chalmers Manufacturing Company.

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*Rotating biological contactor, *Hydraulic loading, Milwaukee

27 Abstract The Milwaukee Metropolitan Sewerage Commission, in conjunction with the Allis Chalmers Research Division, installed a rotating biological contactor (RBC) to treat municipal sewage. The RBC obtained in excess of 90% BOD removal at loading rates of 350 to 400 lbs COD per day per 1000 ft^3 of disc volume, Nitrogen was shown to be removed in a ratio of 1:25, nitrogen to COD. Percent BOD removal was consistently 5% greater than percent COD removal. Treatment efficiency was increased with increased detention time, and decreased by: (1) lower disc speed; (2) lower strength wastes; and (3) high hydraulic loading. Recovery from periods of high hydraulic loading was extremely quick. Further planned investigations included isolation and identification of individual species of microorganisms and comparison with the microorganisms of activated sludge and trickling filters. (Lowry-Texas)

(WRSIC abstract)

Abstractor Mark V. Lowry | Institution Texas Univ, Austin

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I. INTRODUCTION

The purpose of FWPCA Contract 14-12-24, Phase IV, was to demonstrate the feasibility of treating municipal sewage with the Rotating Biological Contactor (RBC). A pilot scale RBC previously constructed for the FWPCA was modified and installed at the Jones Island sewage treatment plant of the Milwaukee Metropolitan Sewerage Commission. Previous laboratory testing on synthetic waste indicated that 80 to 90% removal of COD could be obtained with loadings up to 500 lb. COD/1000 ft^3 of disc volume/day when used in conjunction with settling tanks.

Another objective of the project was the analyzing of the RBC mixed liquor as it flowed from the unit to attain an indication of the extent of treatment which may be expected from the in-line plant which is under construction as Phase II of this contract.

Two independent variables, feed rate and rate of disc rotation, were controlled. Another independent variable, sewage strength, could not be controlled. Throughout the project a secondary settling tank was in operation and in the later weeks primary clarification was used.

The level of treatment by the RBC on domestic waste is indicated by the chemical oxygen demand, nitrogen, phosphorus, and suspended solids removal as determined under this contract.

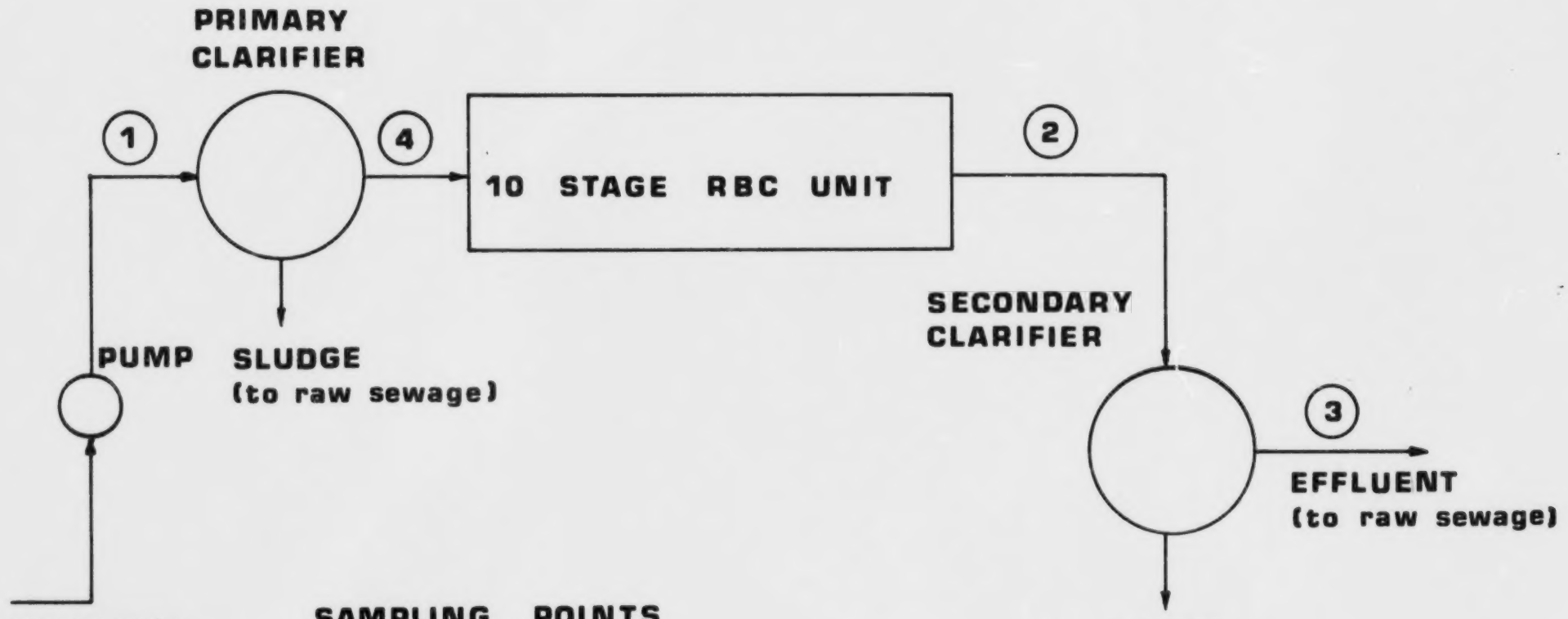
II. SUMMARY AND CONCLUSIONS

The RBC system effectively treated domestic sewage at high loading rates. Lower loadings to evaluate nitrification and oxidation capacity of the unit were not used.

Fine screening is the primary treatment used at the Jones Island treatment plant. It was adequate primary treatment for the RBC to work effectively. Settling was used as a primary treatment preceding the RBC to determine if overall performance was improved. The influent to the primary clarifier was screened raw sewage. It was used because all material removed in fine screening would have been removed in settling and that material could have disabled the pumps periodically.

The following conclusions were noted in the performance of the RBC system at Jones Island:

1. Ninety percent COD removal was attained at a loading around 350 to 400 pounds COD per thousand cubic feet of disc volume per day using Milwaukee sewage.
2. Percent BOD removed was about five percent greater than the percent COD removed.
3. The percent COD removal increases with increasing residence time. The rate of COD reduction decreases as residence time increases. A good system should use an optimum time for power consumed per unit COD reduction.
4. The pounds of COD removed per day increases with the pounds of COD applied. In other words, the higher the pounds of



SAMPLING POINTS

1. Screened raw sewage
2. RBC Mixed Liquor
3. Secondary clarifier effluent
4. Primary clarifier effluent

Figure 1. RBC SYSTEM DIAGRAM

COD loading the greater the COD removal.

5. The pounds of COD oxidized increase with the pounds of COD applied.
6. The removal of Kjeldahl nitrogen compared to the removal of COD is in a ratio of about 1:25 nitrogen to COD removed.
7. Lower disc speed resulted in a slightly lower COD reduction. At higher loading rates it might be expected that the efficiency would be decreased still more at the same disc speed.
8. Lower strength wastes have a lower value of pounds removed per pound applied. So increasing the hydraulic loading decreases efficiency.
9. Recovery from overloading - even extended overloads - is very rapid. Within a few hours efficiency is back at levels expected for the lower loadings.

III. JONES ISLAND SYSTEM

A. SYSTEM DESCRIPTION

The flow diagram for the RBC unit at Jones Island is shown in Figure 1. Raw sewage after fine screening (drum with 3/32" x 2" slots) was pumped to the primary clarifier. Sewage flowed by gravity to the ten stage RBC for secondary treatment. Treated sewage overflowed from the unit to a secondary clarifier. The sludge from both clarifiers and the effluent from the secondary clarifier were returned to the screened raw sewage. The primary clarifier was operated for only the

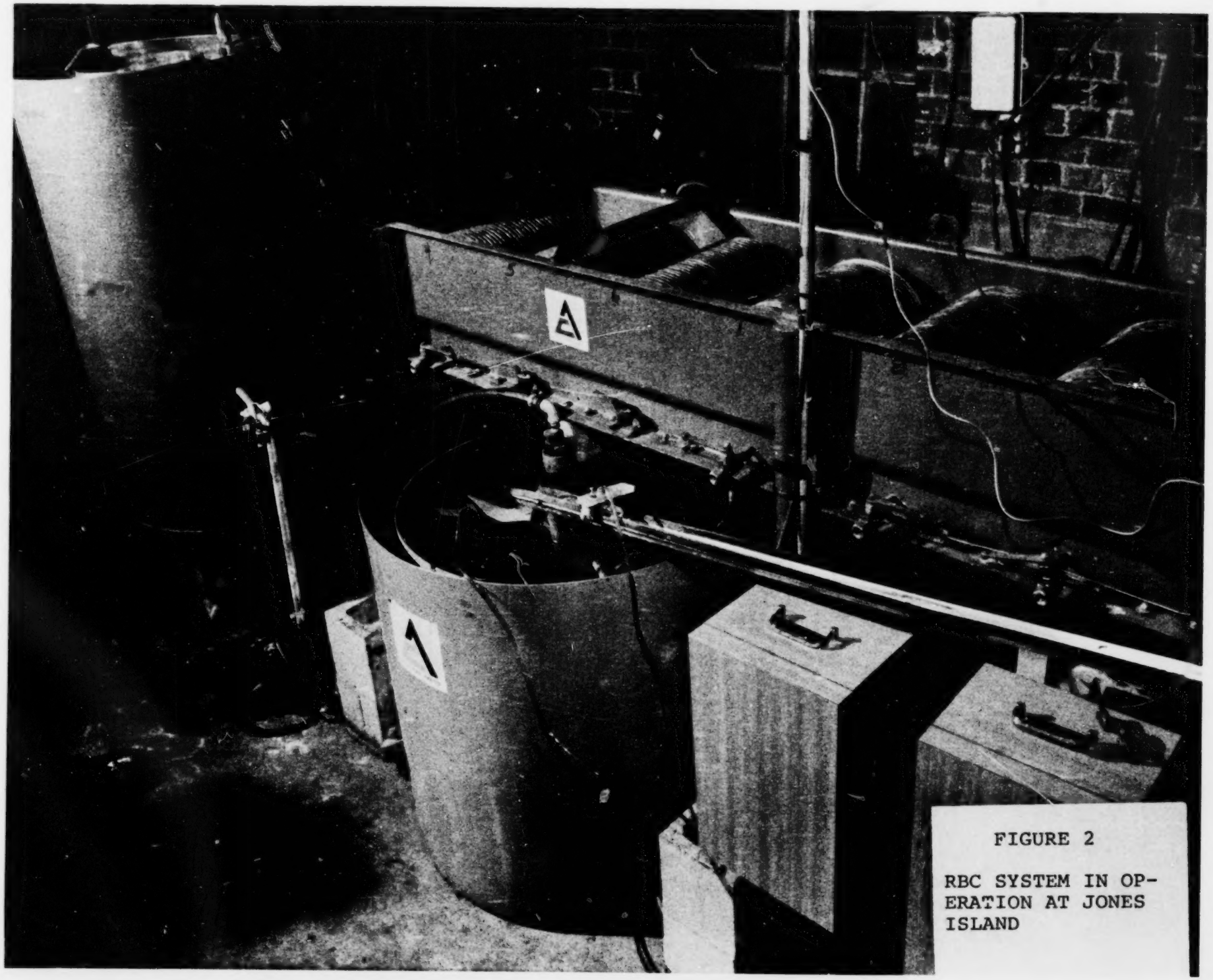


FIGURE 2

RBC SYSTEM IN OPERATION AT JONES ISLAND

last two weeks of the program because of a delay in delivery by the fabricator.

Figure 2 is a photograph of the units as operated at Jones Island. The primary clarifier is to the left. The RBC is followed by an effluent trough taking the RBC mixed liquor to the secondary clarifier beneath the RBC unit.

B. CLARIFIERS

The primary and secondary clarifiers are shown in Figures 3 and 4. The primary clarifier was constructed with a trap to retain floating solids so they would not be carried over into the RBC unit. Screened raw sewage was pumped into the clarifier at the center of the tank and flowed over a weir to an effluent channel with a 45° bottom slope. This primary effluent flowed to the RBC at approximately the same rate as the sewage was pumped in, which was the flow rate for the test run being analyzed. Sludge and scum were generally removed once a day from the primary clarifier.

The secondary clarifier received the RBC effluent near the bottom of the tank by means of a four-inch tube at the center of the tank. The sludge was pumped out up the center through a one-inch pipe which also served as a scraper to help concentrate the sludge. Effluent flowed over a weir at the side of the tank and was disposed of in the channel from the fine screen house. During high flows sludge was drawn off

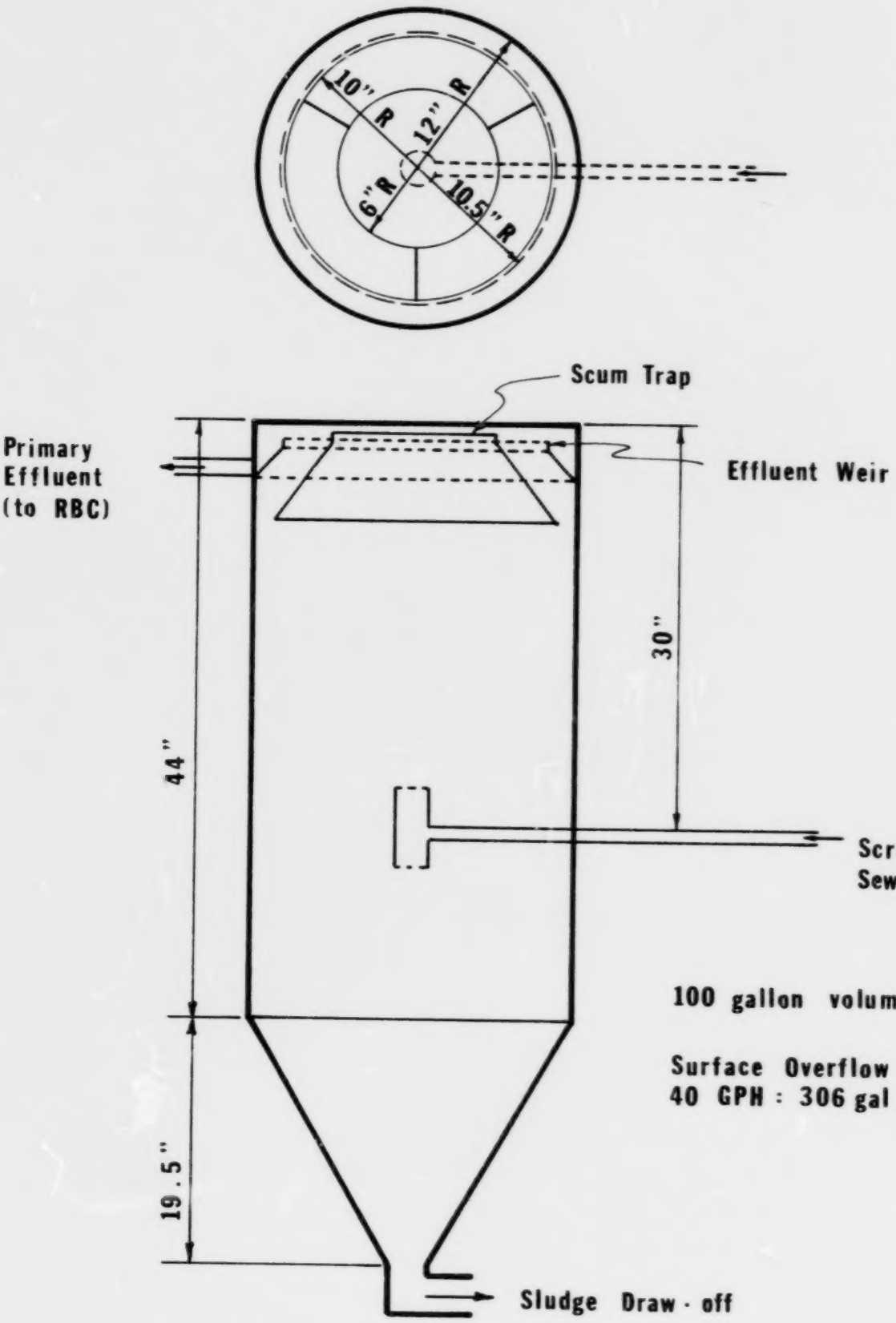
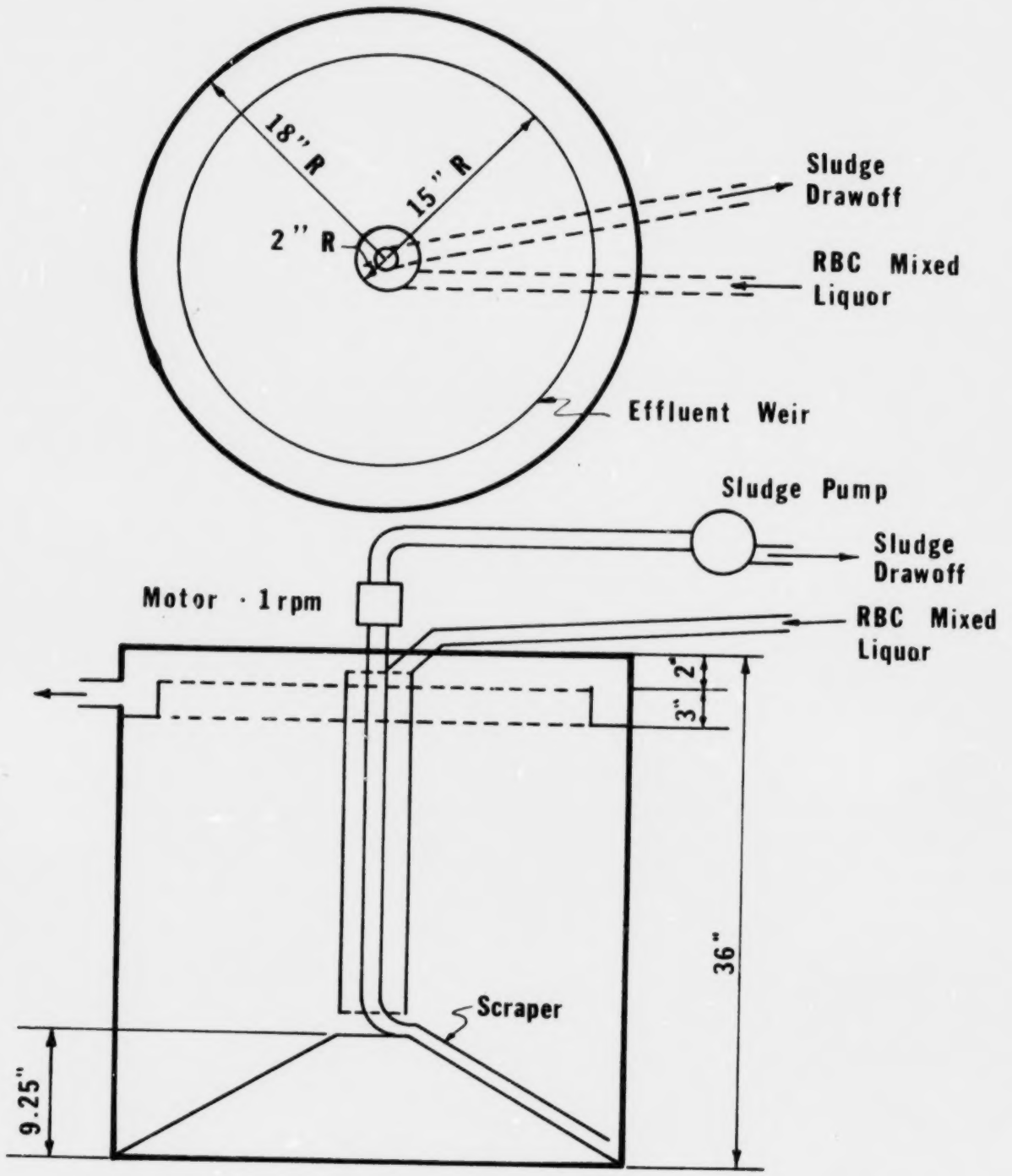


Figure 3. PRIMARY CLARIFIER



150 gallon volume

Surface Overflow Rate at 40 GPH: 136 gal / day / ft^2

Figure 4. SECONDARY CLARIFIER

periodically when the pump was activated by a timer. During low flows when little sludge was produced the sludge was pumped out only once a day to prevent excessive drawdown of the clarifier. Sludge volumes were not measured except as settleable solids in the mixed liquor.

C. TEN-STAGE RBC UNIT

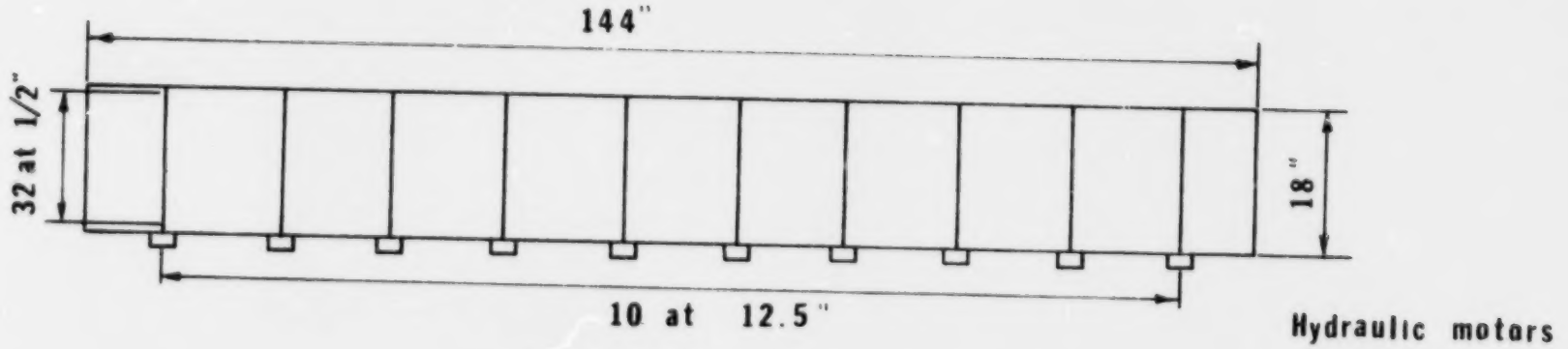
The RBC unit (Figure 5) consists of ten rows of 32 discs each. The discs are one-foot in diameter and spaced at one-half inch center to center. The discs are rotated by a hydraulic drive system in a tank (12'l x 1.5'w x 1'd) with a contoured bottom. The volume of water held by the tank under operating conditions used is about forty gallons. The cubic feet of disc volume, measured as the cylinder formed by the outside edges of a set of discs, is 10.5 cubic feet. A heavy growth of slime as shown in Figure 6 was evident on the discs most of the time.

Waste was introduced to the RBC either by gravity flow from the primary clarifier or by pumping sewage from the channel following fine screening. Overflow from the RBC was carried by a trough to the secondary clarifier.

IV. SAMPLING AND ANALYTICAL PROCEDURES

A. SAMPLING POINTS AND INSTRUMENTATION

Four sampling points were selected as significant to the evaluation of the performance of the RBC system. (Figure 1)



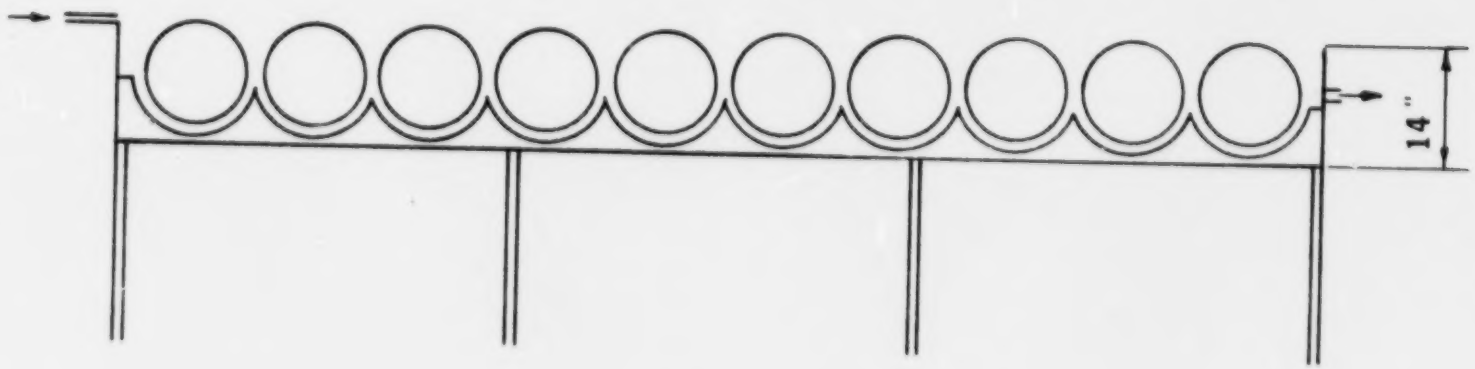


Figure 5. RBC UNIT

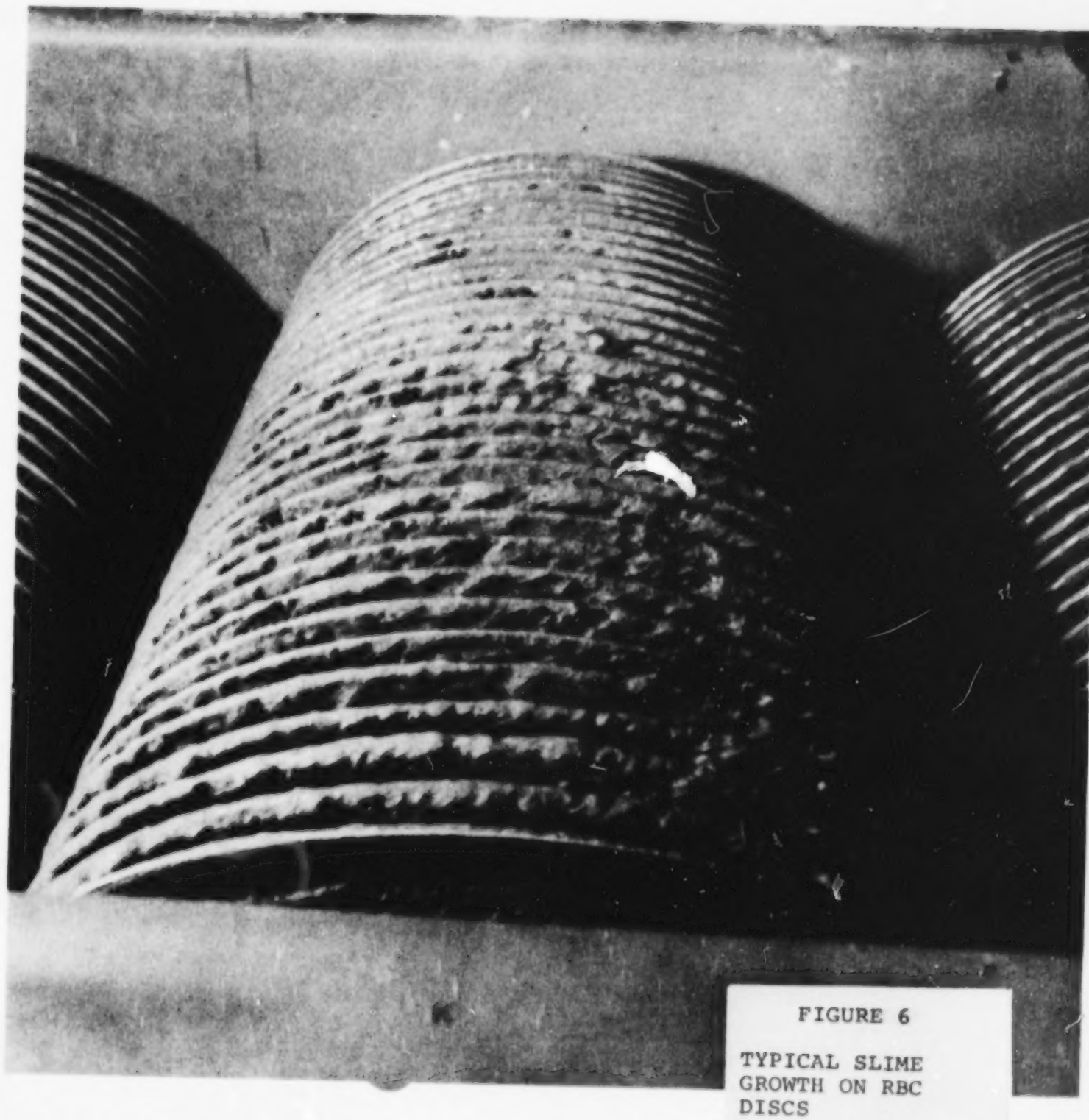


FIGURE 6

TYPICAL SLIME GROWTH ON RBC DISCS

The first was a sample of the screened raw sewage pumped from the channel from the fine screen house. The second was a sample of the RBC mixed liquor overflow. The third was a sample of the secondary clarifier effluent which in a plant would be discharged to a receiving body of water. The fourth was the settled raw sewage which was the influent to the RBC unit when the primary clarifier was in operation.

Three Brailsford composite samplers[1] were installed to take samples from the first three points mentioned above. Large chunks of solids periodically plugged the samplers and prevented them from collecting twenty-four hour composite samples of the raw sewage and RBC effluent. The sample from the secondary clarifier had large particles settled out so the sampler operated well. When it was not possible to get the twenty-four hour composite, four samples were taken manually each hour for four hours and composited.

B. LABORATORY ANALYSES

The determinations run on the samples, the frequency and locations of sampling for analyses are listed in Table I.

1. Samples for dissolved constituents of the water were filtered through #4 Whatman[1] and .45 micron Millipore[1] filters and then composited. These samples were used for dissolved phosphorus, orthophosphate, ammonia, nitrite, and nitrate analyses.

---

[1] Mention of commercial products does not imply endorsement by the FWPCA nor the Contractor.

TABLE I

ANALYSES PERFORMED ON JONES ISLAND SYSTEM

	Frequency	Sampling Points
Temperature	Continuous	1, 2
pH	"	1, 2
Dissolved Oxygen	"	1, 2
Chemical Oxygen Demand	Daily	1, 2, 3, 4
Settleable Solids	"	1, 2, 3, 4
Total Suspended Solids	Weekly	1, 2, 3, 4
Volatile Suspended Solids	"	1, 2, 3, 4
Biochemical Oxygen Demand	"	1, 2, 3, 4
Total Phosphorus	"	1, 2, 3, 4
Dissolved Phosphorus	"	1, 2
Orthophosphate	"	1, 2
Kjeldahl Nitrogen	"	1, 2, 3, 4
Ammonia Nitrogen	"	1, 2
Nitrite Nitrogen	"	1, 2
Nitrate Nitrogen	"	1, 2
Turbidity	Daily	1, 2, 3, 4

2. Unfiltered samples were used for COD, BOD, Kjeldahl Nitrogen, suspended solids (total and volatile), total phosphorus and settleable solids.

3. Temperature, dissolved oxygen, and pH were continuously recorded on influent to and effluent from the RBC unit. A daily average was taken as the determination for the day. The set-up for the meters and recorders is shown in the photograph (Figure 7). The meter used for dissolved oxygen was a YSI Oxygen Analyzer.[1] No significant problems were encountered in its operation. Occasionally grease coated the membrane, but it was changed often enough to prevent extended error in readings. The pH meters were Corning[1] instruments. Some problems were encountered in their use. Sewage was splashed into the calomel electrode so it had to be cleaned out periodically to keep it in working condition. One glass electrode was apparently scratched in use so for a short time - until a new electrode was installed - pH readings on the effluent were not recorded.

4. All tests were run according to Standard Methods procedures except for some modifications in suspended solids, total phosphorus and turbidity.

   Turbidity was run on a Hach Laboratory Tubidimeter (Model 1860).[1] The meter was standardized against a

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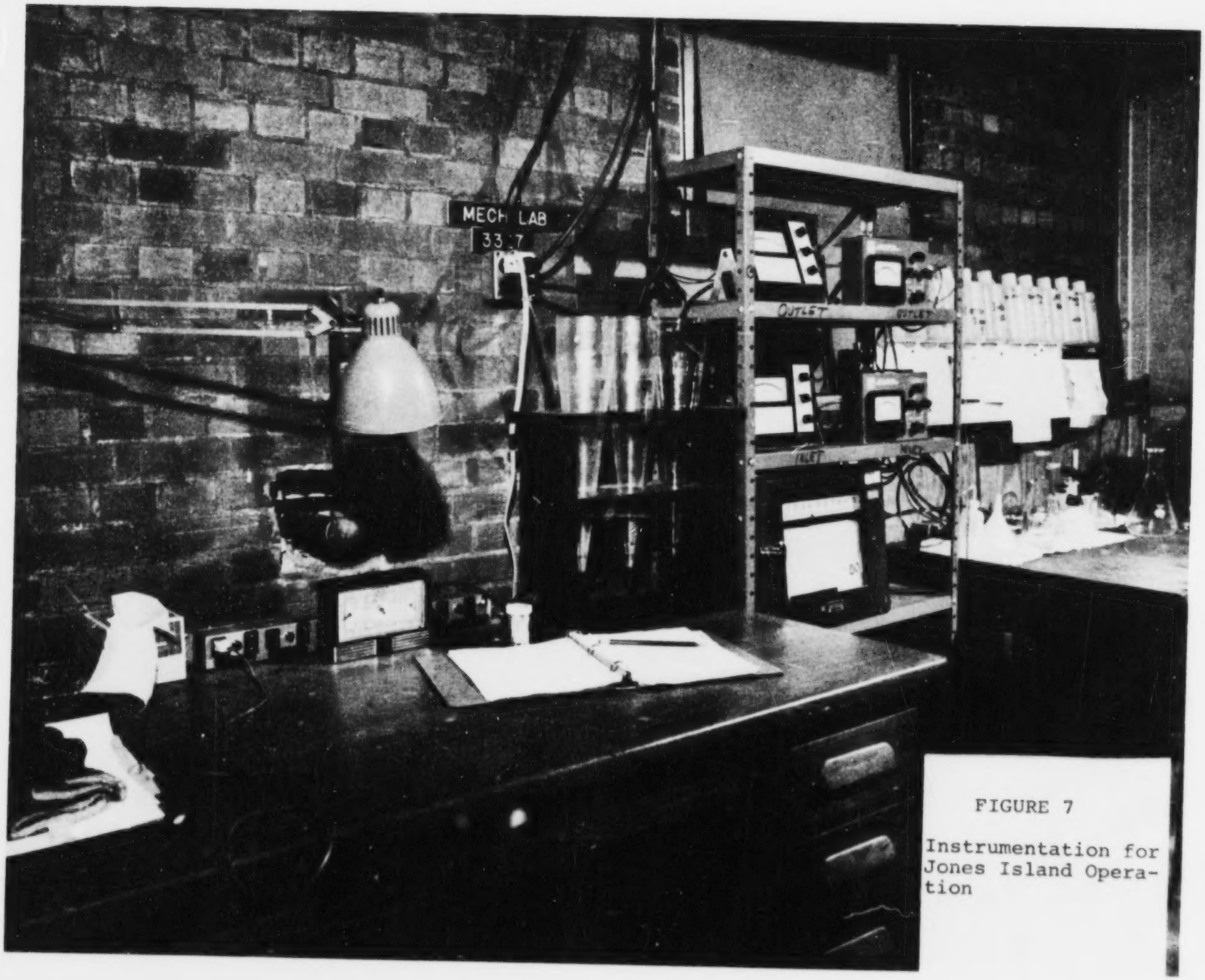

FIGURE 7

Instrumentation for Jones Island Operation

cylinder having a known turbidity - sixty Jackson Turbidity Units - and sample turbidity was determined relative to the standard.

Suspended solids were analyzed using a Reeve Angel[1] glass fiber filter with a Celite[1] mat in the Gooch crucible instead of the asbestos filter which is recommended in Standard Methods. The glass fiber filter assures uniformity of filter while the Celite mat prevents the loss of fine suspended solids around the edge of the filter. The procedure used for the rest of the preparation and for analysis was not changed from that in Standard Methods.

Total Phosphorus was analyzed using a digestion procedure. To a 50 milliliter sample 6 ml of 1 + 1 H_2SO_4 and 5 ml of concentrated HNO_3 were added. The samples were boiled for about fifteen minutes after SO_3 fumes starting coming off. After cooling, distilled water was added and the acidity was neutralized to phenolphthalein pink with 25% NaOH. Samples were returned to slight acidity using the Strong Acid Reagent from Standard Methods Phosphorus procedure. The rest of the analysis was one outlined in Standard Methods.

For some of the analyses there were several methods available. The determinations and methods used are:

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[1] Mention of commercial products does not imply endorsement by the FWPCA nor the Contractor.

for Ammonia, direct Nesslerization was used; for Nitrate, the Brucine method was used; and for Phosphorus (all determinations), the aminonaphtholsulfonic acid method was used.

V. OBSERVATIONS AND RESULTS

The data from the project is tabulated in Tables 2, 3, 4, 5, 6, and 7.

A. Table 2 gives the operating conditions and any significant occurrences that affected the operation or performance of the unit. Twice the hydraulic motors used to drive the RBC disc assemblies developed leaks and the unit had to be shut down temporarily. The COD's at those times were extremely high reflecting the COD of the oil. At the time of the first leak after the oil was no longer leaking into the unit there was a rapid recovery to the efficiency expected at the loadings being used. The unit was shutdown completely at the end of the test program before the second leak was repaired. Results from the first and last weeks will not be included in any analyses because of the COD increasing due to the oil leak. When there was enough rain for runoff to occur, overloading the combined sewers of Milwaukee, the strength of the sewage coming to the unit was generally lower than during dry weather flow.

TABLE 2 - FLOW CONDITIONS

DATE	FLOW RATE	ROTATION RATE	COMMENTS
Nov. 4	40 GPH	30 RPM	
5			
6			Grease and oil
7			"
8			"
9			Oil leak from hydraulic
10			motors.
11			
12			
13			
14			
15			
16			Rain
17			Rain
			Rain
18			
19			
20	80 GPH		
21			
22			
23			
24			
25			
26			
27			
28			Rain
29			Snow
30			
Dec. 1			
2			
3			
4			
5	240 GPH		
6			
7			
8			
9			
10			
11			Inlet pump off. No samples.
12			Fuse Blown. No samples.
13			ph meter out
14			No tests "
15			"
			"

TABLE 2 - FLOW CONDITIONS (continued)

DATE	FLOW RATE	ROTATION RATE	COMMENTS
Dec.16	240 GPH	30 rpm	pH Meter out
17			Fuse Blown. No samples
18			Rain
19	40 GPH	15 rpm	Rain
20			
21			Snow
22			
23			
24			
25			
26			
27			
28			Snow
29			
30			
31			
Jan. 1			
2			
3	40 GPH	30 rpm	
4			
5			Primary settling installed
6			
7			
8			
9			
10			
11			
12			
13	80 GPH		
14			
15			Snow, Rain
16			Rain
17			Snow
18			
19			Oil Leak from motor
20			Oil Leak from motor
21			Samples with oil
22			" Shutdown
23			

TABLE 3 - PHYSICAL CHARACTERISTICS AND pH

DATE	TEMPERATURE °C. AVERAGE DAILY		pH AVERAGE DAILY		TURBIDITY JACKSON TURBIDITY UNITS			
	SCREEN. RAW SEWAGE	RBC MIXED LIQUOR	SCREEN. RAW SEWAGE	RBC MIXED LIQUOR	SCREEN. RAW SEWAGE	PRIM. CLARIF.	RBC MIXED LIQUOR	SETT. EFFL-ENT
Nov. 4	19.5	20.2	7.6	7.6	82		20	43
5	19.1	20.4	7.8	7.7	75			
6	17.0	19.7	7.9	7.9				
7								
8	18.9	18.6	7.7	7.8				
9	17.8	18.1	7.2	7.6				
10	16.8	17.9	7.6	7.9	50		33	67
11	17.8	17.7	8.3	7.9	180		120	17
12	18.2	16.4	7.9	8.0	120		53	25
13	18.9	18.8	7.9	7.7	132		25	16
14	19.1	19.8	7.3	7.6	140		45	18
15	18.1	19.8	7.8	8.3	122		24	21
16	17.9	19.2	7.3	8.0	72		32	13
17	16.5	17.1	8.1	7.9	75		56	15
18	18.0	18.0	8.3	7.3	48		16	6
19	18.2	17.0	7.8	7.6	72		42	8
20	17.9	16.5	7.9	6.8	148		36	16
21	18.1	17.7	8.4	7.3	145		73	40
22	18.1	17.9	8.2	7.8	173		22	44
23	18.0	19.0	7.7	7.1	138		32	18
24	17.5	18.5	7.7	7.8	105		22	20
25	17.8	18.0	8.3	7.7	82		42	12
26	18.0	19.0	8.1	7.4	80		42	28
27	18.8	17.7	7.8	7.2	48		25	17
28	16.5	17.9	7.6	7.7	97		30	25
29	15.9	16.2	8.7	7.7	45		19	8
30	16.0	16.0	8.1	7.8	48		18	9
Dec. 1	16.0	16.0	8.2	7.9	44		15	9
2	16.0	17.0	8.2	7.8	47		28	12
3	18.0	18.7	8.0	7.7	44		28	12
4	18.1	17.8	8.2	7.5	46		31	23
5	17.7	16.8	8.2	7.4	39		40	41
6	17.2	16.1	7.1	7.8	59		40	45
7	16.6	16.1	6.8	7.2	55		27	51
8	15.0	15.0	7.6	8.1	66		63	54
9	16.0	16.1	8.0	7.8	64		39	35
10								
11								
12	17.0	18.2	7.8		24		23	28
13	16.8	16.8	8.0					
14	15.3	15.7	7.2		95		52	51
15	15.0	15.0	7.7		82		59	54

TABLE 3 - PHYSICAL CHARACTERISTICS AND pH

DATE	TEMPERATURE °C AVERAGE DAILY		pH AVERAGE DAILY		TURBIDITY JACKSON TURBIDITY UNITS			
	SCREEN. RAW SEWAGE	RBC MIXED LIQUOR	SCREEN. RAW SEWAGE	RBC MIXED LIQUOR	SCREEN. RAW SEWAGE	PRIM. CLARIF.	RBC MIXED LIQUOR	SETT. EFFLUENT
Dec. 16	15.9	15.5	8.2		100		59	77
17								
18	16.7	17.1	7.8	7.7	87		41	95
19	13.2	14.0	8.1	8.2	75		26	95
20	16.0	17.5	7.9	7.7	74		41	40
21	15.2	16.3	7.7	7.5	70		20	33
22	10.6	14.0	7.5	6.4	47		4	18
23	14.5	15.6	8.5	6.5	120		40	14
24	13.5	13.5	7.8	6.9	98		22	12
25	12.9	11.3	7.9	6.5	42		34	21
26	13.4	14.4	7.9	6.5	41		38	11
27	8.8	12.2	8.2	6.3	83		23	21
28	11.1	14.0	8.1	7.9	64		28	10
29	13.1	15.1	8.2	7.9	61		24	8
30	14.9	16.5	7.8	7.3	49		14	14
31	12.3	10.0	8.0	7.9	95			21
Jan. 1	10.0	11.0	7.4	7.3	41			11
2	12.2	12.3	7.4	7.7	70		27	12
3	13.1	12.7	7.5	7.7	67		40	28
4	11.3	10.5	7.1	7.8	100		31	14
5	12.0	11.7	7.3	7.8		90	35	12
6	13.5	16.9	8.4	6.4	56	69	64	19
7	14.3	15.3	7.5	6.3	62	100	48	9
8	14.5	16.0	7.5	7.8	87	76	42	14
9	14.2	14.1	7.3	7.8	100	100	25	17
10	13.0	12.5	7.6	7.8	45	84	34	14
11	12.9	12.3	7.6	7.8	44	77	10	8
12	12.0	12.2	7.4	7.7	53	56	28	8
13	14.0	15.3	8.6	7.7	54	90	21	5
14	14.2	16.3	7.5	7.8	90	90	16	13
15	13.4	14.6	7.2	7.5	104	79	22	18
16	13.2	15.7	7.6	7.7				
17	13.7	15.3	7.9	7.8	102	82	14	10
18	12.9	14.6	8.6	8.0	76	56	18	15
19								
20								
21	14.1	16.0	7.6	7.8	84	130	60	75
22					76	65	92	52
23								

TABLE 4 - OXYGEN PARAMETERS

DATE	DISSOLVED OXYGEN mg/l DO		CHEMICAL OXYGEN DEMAND mg/l COD				BIOCHEMICAL OXYGEN DEMAND mg/l BOD		
	Screen. Sewage	RBC Mix Liquor	Screen. Sewage	Prim. Clarif.	RBC Mix Liquor	Sett. Efflu.	Screen. Sewage	Raw Mix Liquor	Sett. Efflu.
Nov. 4	0.9	4.2	672		1248	374			
5	1.1	3.3	1022		45176		498		
6	1.3	4.7	910		4800	3346	393	782	499
7									
8	1.4	4.2							
9	0.5	3.8							
10	0.9	4.8	300		1260	272	225	282	95
11	0.6	4.0	607		467	81	515	235	74
12	0.8	3.2	759		293	159	469	257	71
13	0.8	4.3	526		391	108			
14	0.8	4.2	855		759	159	551	381	81
15	0.8	4.1	789		717	199			
16	1.2	5.0	661		741	159			
17	1.5	5.4	343		383	120	190	164	41
18	1.0	5.9	265		180	42	141	92	20
19	1.2	6.5	597		691	95			
20	1.0	2.8	543		268	169	256	150	67
21	0.9	2.2	771		429	228	275	260	116
22	0.8	4.4	611		486	297			
23	0.6	4.2	589		413	141			
24	0.8	5.1	597		379	168	437	154	69
25	0.8	3.8	425		341	138	340	176	66
26	0.7	4.1	653		518	203	307	241	76
27	0.7	3.5	622		363	155	326	164	70
28	1.0	3.6	476		841	183			
29	1.7	2.7	365		119	95			
30	1.1	4.9	299		390	118			
Dec. 1	1.5	5.0	405		238	183			
2	1.0	3.6	344		201	98	210	101	46

TABLE 4 - OXYGEN PARAMETERS (continued)

DATE	DISSOLVED OXYGEN mg/l DO		CHEMICAL OXYGEN DEMAND mg/l COD				BIOCHEMICAL OXYGEN DEMAND mg/l BOD		
	Screen. Sewage	RBC Mix Liquor	Screen. Sewage	Prim. Clarif.	RBC Mix Liquor	Sett. Efflu.	Screen. Sewage	Raw Mix Liquor	Sett. Efflu.
Dec. 3	1.5	6.2	557		255	133	369	128	68
4	0.9	3.6	625		401	149	387	163	76
5	0.8	2.2	653		496	401			
6	0.6	2.1	685		480	417			
7	1.4	2.8	613		590	443			
8	0.5	3.4	368		335	272			
9	0.7	1.3	225		190	186			
10									
11									
12	0.6	3.3	607		494	396	415	260	
13	1.1	3.0							
14	1.0	2.3	685		520	441			
15	2.1	4.0	504		457	354			
16	0.6	3.2	779		708	527			
17									
18	1.4	4.1	1050		651	502	556	428	290
19	3.5	3.7	643		721	416	425	350	
20	1.3	1.2	384		227	188			
21	0.6	2.8	455		588	243			
22	2.3	0.3	596		761	149			
23	1.4	1.1	823		721	150			
24	0.9	0.6	505		603	141			
25	1.1	0.4	580		588	329			
26	0.7	0.3	353		458	209	222	140	40
27	5.4	0.7	457		547	165			
28	5.2	5.8	711		1153	195			
29	3.4	4.6	696		367	150			
30	0.4	0.5	658		233	283			
31	1.9	3.5	633			208			

TABLE 4 - OXYGEN PARAMETERS (continued)

DATE	DISSOLVED OXYGEN mg/l DO		CHEMICAL OXYGEN DEMAND mg/l COD				BIOCHEMICAL OXYGEN DEMAND mg/l BOD		
	Screen. Sewage	RBC Mix Liquor	Screen. Sewage	Prim. Clarif.	RBC Mix Liquor	Sett. Efflu.	Screen. Sewage	Raw Mix Liquor	Sett. Efflu.
Jan.1	1.5	5.8	283			166			
2	1.5	6.7	765		625	189	436	252	59
3	1.2	7.0	736		600	201			
4	1.5	8.7	559			119			
5	0.3	7.9		263	551	91			
6	0.1	1.7	206	280	296	91			
7	0.2	2.8	392	578	374	82			
8	0.2	5.7	849	551	339	151			
9	0.5	5.1	938	669	286	163	690 *	117	64
10	0.3	5.3	751	673	335	122			
11	0.2	8.0	661	567	485	98			
12	0.0	8.1	327	322	355	106			
13	0.5	6.0	277	522	212	65			
14	0.4	3.1	498	498	98	61			
15	0.0	2.5	864	612	280	232	715 *	168	143
16	0.0	3.0	728	484	384	232			
17	0.0	2.7	737			134			
18	0.0	2.0	498	445	324	158			
19									
20									
21	1.4	3.6	494	583	858	635			
22			702	488	1100	508			
23									

* Primary Clarifier
Jan. 9 386 mg/l BOD
Jan.15 652 mg/l BOD

TABLE 5 - SOLIDS

DATE	SETTLEABLE SOLIDS ml/l				SUSPENDED SOLIDS mg/l			VOLATILE SUSPENDED SOLID mg/l		
	SCREEN. SEWAGE	PRIM. CLARIF.	RBC MIX LIQUOR	SETT. EFFLU.	SCREEN. SEWAGE	RBC MIX LIQUOR	SETT. EFFLU.	SCREEN. SEWAGE	RBC MIX LIQUOR	SETT. EFFLU.
Nov. 4										
5	10.0		>40							
6	11.5		26.0							
7	10.0		16.0							
8										
9										
10					140	322	136	138	150	132
11	9.8		27.0							
12	9.7		21.0		582	442	58	326	388	56
13	10.0		26.0							
14	9.0		30.0		308	684	78	244	544	66
15	6.0		30.5							
16	6.5		23.0							
17	3.5		6.5							
18	10.0		13.0		155	79	27	93	43	20
19	9.0		18.0		270	422	39	242	402	39
20	15.0		11.0		276	364	60	252	184	60
21	16.1		25.0	0.6						
22	10.0		18.3							
23	10.0		21.0							
24	11.0		21.0		282	256	49	129	206	48
25	11.0		24.8							
26	10.5		20.5	0.1	210	298	18	190	252	16
27	7.5		9.5	0.0	160	394	75		322	64
28	9.0		19.0	1.0	362	300	70	188	152	58
29	6.0		25.0							
30	10.0		19.0							
Dec. 1	4.0		8.0		240	192	76	184	176	68
2	9.0		11.0		208	177	71	168	108	63

TABLE 5 - SOLIDS (continued)

DATE	SETTLEABLE SOLIDS ml/l			SUSPENDED SOLIDS mg/l			VOLATILE SUSPENDED SOLIDS mg/l		
	SCREEN. SEWAGE	PRIM. CLARIF.	RBC MIX LIQUOR / SETT. EFFLU.	SCREEN. SEWAGE	RBC MIX LIQUOR	SETT. EFFLU.	SCREEN. SEWAGE	RBC MIX LIQUOR	SETT. EFFLU.
Dec. 3	19.0		15.0 / 0.1	390	230	51	216	157	50
4									
5	10.0		19.0 / 1.5	326	305	83	202	204	63
6	10.0		11.0 / 1.5						
7	9.0		13.0 / 3.0						
8	8.0		10.0 / 1.8						
9	7.5		9.5 / 1.0						
10									
11									
12	8.0		12.0 / 1.7	304	202	108	212	168	89
13	12.0		16.2 / 1.7						
14									
15	16.0		20.0 / 1.0						
16	10.5		12.0 / 2.0						
17									
18	11.0		14.0 / 2.0	1445	292	144	1315	256	140
19	9.5		10.7 / 0.5	300	348	148	252	280	136
20	9.5		4.5						
21	4.3		14.3						
22	4.6		15.0 / 0.2						
23	7.7		15.1						
24	8.3		7.0						
25	1.5		3.5						
26	9.5		10.5	106	184	24	106	184	24
27	5.8		16.0						
28	3.5		11.5						
29	4.3		3.1						
30	9.5		10.0						
31	7.5		4.0 / 0.0						
Jan. 1	7.0		0.4						
2	11.5		19.5	366	598	54	288	464	46
3	10.0		18.0						

TABLE 5 - SOLIDS (continued)

DATE	SETTLEABLE SOLIDS ml/l				SUSPENDED SOLIDS mg/l			VOLATILE SUSPENDED SOLIDS mg/l		
	SCREEN. SEWAGE	PRIM. CLARIF.	RBC MIX LIQUOR	SETT. EFFLU.	SCREEN. SEWAGE	RBC MIX LIQUOR	SETT. EFFLU.	SCREEN. SEWAGE	RBC MIX LIQUOR	SETT. EFFLU.
Jan. 4	8.0		13.5							
5	6.0		14.0							
6	10.5		7.0	0.0						
7	12.0		12.0	0.3						
8	9.2	0.0	5.1	0.0						
9	8.5	0.5	28.0	0.5						
10	27.0	0.5	23.2		524 *	160	156	364 *	132	132
11	12.0	0.0	5.0							
12	6.5	0.2	3.7							
13	10.5	3.7	0.0							
14	7.0	4.0	0.2							
15	11.0	2.0	4.7							
16	11.5	1.4	17.0		485 *	117	70	345 *	97	62
17	7.7	1.0	10.0							
18	5.6	0.0	10.0							
19										
20										
21	5.5	3.0	10.0							
22										
23										

*Primary Clarifier

Suspended Solids

Jan. 9 260 mg/l

Jan.15 228 mg/l

Volatile Suspended Solids

Jan. 9 192 mg/l

Jan.15 172 mg/l

TABLE 6 - NITROGEN

DATE	KJELDAHL NITROGEN mg/l			NH_3 - N mg/l		NO_2^--N mg/l		NO_3^- - N mg/l	
	SCREEN. SEWAGE	RBC MIX LIQUOR	SETT. EFFLU.	SCREEN. SEWAGE	SETT. EFFLU.	SCREEN. SEWAGE	SETT. EFFLU.	SCREEN. SEWAGE	SETT. EFFLU.
Nov. 5	34.0			19	13	ND	ND	0.4	0.1
10	31.3	47.9	26.7						
11	47.2	41.7	28.5						
12	49.7	37.8	23.1	17	10	.06	ND	0.2	0.2
14	44.8	61.9	20.2	18	11	.05	ND	0.6	0.2
17	22.4	30.2	15.3						
18	30.9	25.5	29.0	25	22	.08	.09	0.2	0.2
21	50.3	21.7	21.6	21	13	.12	ND	0.5	ND
22	34.4	35.4	19.9						
25	35.8	37.4	23.7	23	16	.08	ND	0.7	ND
26	37.8	39.1	21.6						
Dec. 1	37.1	32.9	22.8						
2	28.6	24.2	22.3	22	17	.16	.01	0.3	ND
5	36.0	30.0	27.0						
9	35.6	29.3	29.8						
12	42.6	35.0	30.8						
18	55.9	38.5	38.3	11	16				
19	44.7	35.3	24.3	11	16	.01	.07	2.0	0.4
26	33.7	36.0	27.6	22	19	.11	.01	0.9	ND
Jan. 2	50.8	49.3	18.4	23	17	.08	.06	1.8	ND
9	52.6 *	29.4	22.5	22	17	.05	.01	ND	ND
15	37.3 *	27.0	22.5	12	21	.06	.01	1.2	ND
22									

Primary Clarifier - Jan. 9 41.6 mg/l N_k-N
Jan.15 49.2 mg/l N_k-N

ND - Not Detectable

TABLE 7 - PHOSPHORUS

DATE	mg/l-P ORTHO-PHOSPHATE SCREEN. SEWAGE	mg/l-P ORTHO-PHOSPHATE SETTLED EFFLUENT	mg/l-P DISSOLVED PHOSPHORUS SCREEN. SEWAGE	mg/l-P DISSOLVED PHOSPHORUS SETTLED EFFLUENT	mg/l-P TOTAL PHOSPHORUS SCREEN. SEWAGE	mg/l-P TOTAL PHOSPHORUS MIXED LIQUOR	mg/l-P TOTAL PHOSPHORUS SETTLED EFFLUENT
Nov. 5	3.4	1.8	4.0	2.8			
11					13	10	7
12	3.8	2.2	4.6	2.4	17	14	6
14	3.3	1.2	3.8	1.3	14	10	6
17					6	6	2.5
18	3.0	3.1	4.3	4.0	8	6	4
19					9	7	4
21	2.6	1.6	3.2	1.7	10	9	5
25	4.0	3.1	5.3	5.3	10	8	6
26					12	10	
Dec. 1							
2	3.4	2.8	3.7	3.0	8	6	6
4					7	5	3
9					10	8	5
12	4.6	3.9	4.0	3.5	6.8	5.1	1.0
18							
19	2.9	1.2	1.7	1.2	2.1	4.2	1.4
26	3.0	2.2	3.3	2.5	3.9	4.8	1.6
					3.2	1.9	1.8
Jan. 2	7.0	2.3	7.0	2.5	10.0		
9	4.5	2.5	5.2	2.5	6.4 *	3.9	3.4
15	3.5	2.5	3.8	3.0	5.7 *	3.7	3.0
22						5.0	3.2

* Primary Clarifier

Jan. 9 5.7 mg/l Total Phosphorus as P
Jan. 15 6.5 mg/l Total Phosphorus as P

B. Table 3 shows temperature, pH, and turbidity. At the lower temperatures during the colder periods of winter the efficiency of treatment was lower as might be expected in a biological process.

Percent removals were adjusted to 20°C for analytical purposes as will be discussed later. pH varied in a range from 6.4 to 8.6, sometimes increasing through the unit, sometimes decreasing. There appears to be no significance to the change but the range of pH is within a range compatible with biological processes.

C. Table 4 contains the oxygen parameters used. The dissolved oxygen into the unit was generally low - often less than one (1) mg/l. The lower effluent D.O.'s occurred when the disc speed was down to 15 rpm instead of the usual thirty.

COD was measured daily on all samples which were collected. On days of and following rainfall the COD of raw sewage was usually lower than it was on the days immediately preceding a rainfall. Weekend samples, also tended to be lower strength sewage. The ratio of BOD to COD in the raw sewage averaged .64 with a range of .47 to .85. The ratio of BOD to COD in the effluent was lower because more of the biodegradable material had been removed in the process. The average in the effluent of BOD to COD was .46 with a range from 0.19 to 0.91. The BOD to COD ratio of the RBC Mixed Liquor

was 0.50 with a range of 0.31 to 0.87.

D. The solids analyses performed are in Table 5. The settleable solids in the flow from the RBC unit are not considerably higher than that in the raw sewage. The flow following the secondary clarifier has almost no settleable solids indicating that the settling tank worked efficiently. Suspended solids were removed best at the lower flow rates. It might be expected that if the flow was still lower the suspended solids removal would be better.

E. The determinations of nitrogen are shown in Table 6. The concentrations of Kjeldahl nitrogen (N_k) followed the same pattern as COD's. When rainfall diluted the waste the concentration of Kjeldahl nitrogen was low. Ammonia was sometimes most of the Kjeldahl nitrogen especially when the N_k concentration was low. Nitrite and nitrate concentrations in the influent and effluent were usually very low, so obviously nitrification did not take place.

F. Phosphorus analyses are shown in Table 7. All results are expressed in mg/l of phosphorus. The concentrations of the types of phosphorus varied considerably. Lower concentrations seemed to follow rainfalls. Presumably the total phosphorus into the RBC and from the RBC should average out to be approximately equal. The flow from the RBC consistently analyzed about 2 mg/l lower than the influent. It is possible

that some solids were lost in sampling. Another possibility is that the digestion procedure used in the analysis did not completely break up the phosphate containing compounds in the flocculant RBC effluent, while the simpler compounds in the influent were completely digested.

VI. ANALYSIS OF RESULTS

The percent removals of the more important contaminants of waste water are shown in Tables 8 and 9. Table 8 shows the removals in the RBC unit by itself. Table 9 shows the removals attained by the RBC in conjunction with a secondary clarifier. These removals do not take into consideration the variation in temperature.

A. TEMPERATURE CORRECTION

To arrive at a value for removal at 20°C so comparison between the results could be made the following formula for temperature correction, developed by Allis-Chalmers in previous testing on synthetic sewage, was used:

$$\frac{\text{Ln } COD_{20}}{\text{Ln } COD_T} = k^{(20 - T)}$$

where:

T = Temperature, °C,

$\text{Ln } COD_{20}$ = natural log of fraction of COD remaining at 20°C,

$\text{Ln } COD_T$ = natural log of fraction of COD remaining at T°C.

k = reaction constant = 1.07

TABLE 8 - PERCENT REMOVALS THROUGH RBC UNIT ONLY

DATE	CHEMICAL OXYGEN DEMAND	BIOCHEMICAL OXYGEN DEMAND	SUSPENDED SOLIDS	VOLATILE SUSPEND. SOLIDS	KJELDAHL NITROGEN	ORTHO-PHOSP.	DISSOLV. PHOSPHOR.
	COD	BOD	SS	VSS	N_k	OP	DP
Nov.11	23	54	24	-	12		
12	61	45			24	42	48
13	25	-					
14	11	31	-	-	-	64	66
15	9	-					
16	-	-					
17	-	14			-		
18	32	35	49	54	18	-	7
19	-		-	-			
20	51	41	-	27			
21	44				57	38	47
22	20				-		
23	30						
24	37	64	9	-			
25	20	48	-	-	-	23	-
26	21	21	-	-	-		
27	42	50	17	19			
28	-						
29	67						
30	-						
Dec. 1	41	65	20	4	11		
2	42	52	15	36	15	18	19
3	54	65	41	27			
4	36	58					
5	24		6	-	17		
6	30						
7	4						
8	9						
9	16				18		
10							
11							
12	19	37	36	21	18	15	13
13							
14	24						
15	9						
16	9						
17							
18	38	23	80	80	31		
19	-	18	-	-	21	59	29
20	41						
21	-						
22	-						

TABLE 8 - PERCENT REMOVALS THROUGH RBC UNIT ONLY

DATE	COD	BOD	SS	VSS	N_k	OP	DP
Dec. 23	12						
24	-						
25	-						
26	-	37	-	-	-	27	24
27	-						
28	-						
29	47						
30	65						
31							
Jan. 1							
2	18	42	-	-	3	67	64
3	18						
4							
5	-						
6	-						
7	5						
8	60						
9	70	8	38	31	29	44	52
10	55						
11	27						
12	-						
13	23						
14	80						
15	68	77	49	44	45	29	21
16	47						
17							
18	35						

TABLE 9 - PERCENT REMOVALS BY THE COMPLETE SYSTEM

DATE	BIOCHEMICAL OXYGEN DEMAND	CHEMICAL OXYGEN DEMAND	SUSPENDED SOLIDS	VOLATILE SUSPEND. SOLIDS	KJELDAHL NITROGEN	ORTHO-PHOSP.	DISSOLVED PHOSPHOR.	TOTAL PHOS.
	BOD	COD	SS	VSS	N_k	OP	DP	TP
Nov. 4		44.3						
5								
6						47.1	30.0	
7								
8								
9								
10	57.8	9.9	2.8	4.3	14.8			
11	85.6	86.6	90.3	82.8	39.6			
12	84.9	79.1						46.1
13		79.4			53.5	42.1	47.8	64.7
14	85.3	81.4	74.7	73.0	54.9	63.6	65.8	57.2
15		74.8						
16		75.9						
17	78.4	65.0			31.7			60.0
18	85.8	84.2	82.6	78.5	6.1	0.0	7.0	50.0
19		84.1	85.6	83.9				55.6
20	73.8	68.9	78.3	76.2				
21	58	70.4			57.1	38.4	46.9	50.9
22		51.3			42.2			
23		76.1						
24	84.2	71.8	82.7	62.8				
25	80.6	67.3	91.4	91.6	33.8	22.5	0.0	40.0
26	75.3	68.9	53.2	60.0	42.8			
27	78.5	75.1	80.7	69.2				
28		61.5						
29		74.0						
30		60.5						
Dec. 1	79.3	54.8	68.3	63.1	38.6			25.0
2	78.1	71.6	65.9	62.5	22.0	17.7	18.9	57.2
3	81.6	76.1	86.9	76.9				50.0
4	90.3	76.2						
5		38.1	74.5	68.8	25.0			
6		39.1						
7		27.8						
8		26.1						
9		17.3						
10								85.3

TABLE 9 - PERCENT REMOVALS BY THE COMPLETE SYSTEM

DATE	BOD	COD	SS	VSS	N_k	OP	DP	TP
Dec. 11								
12		34.7	64.5	58.0	27.6	15.1	12.5	
13								
14		35.7						
15		29.7						
16		32.5						
17								
18	47.9	52.2	90.6	89.4	31.4			33.3
19		35.3	50.7	46.0	45.7	58.6	29.3	59.0
20		51.1						
21		46.6						
22		75.0						
23		81.8						
24		72.1						
25		43.3						
26	82.0	40.7	77.4	77.4	18.1	26.7	24.2	43.7
27		63.9						
28		72.5						
29		78.4						
30		57.0						
31		67.1						
1		41.4						
2	86.4	75.3	85.2	84.0	63.8	67.1	64.3	66.0
3		72.7						
4		78.7						
5		65.4						
6		55.8						
7		79.1						
8		82.2						
9	90.7	82.6	70.2	63.7	57.2	44.4	51.9	52.4
10		83.7						
11		85.2						
12		67.6						
13		76.5						
14		87.8						
15	80.0	73.2	85.6	82.0	39.7	28.6	21.1	43.8
16								
17								
18								
19								

A reaction constant of 1.07 was used for the domestic waste rather than 1.103 developed by Allis-Chalmers on the synthetic waste made up of dairy whey and nutrients. The lower reaction constant appeared to be more representative of the waste being treated in this testing. The temperature used in the calculation was an average of the influent and effluent flow. This assumes that the average temperature of the mixed liquor gives the approximate rate of biological action. BOD and COD removals corrected to 20°C are shown in Table 10.

Average percent removals at the end of Table 10 were calculated by averaging oxygen demands for screened sewage, RBC mixed liquor and settled effluent. From these averages the overall percent removals were calculated and corrected to 20°C. The temperatures shown are averages of the daily temperatures of the flow through the RBC unit.

B. COD REMOVAL

A plot of pounds per day of COD applied versus pounds per day of COD removed (Figure 8) shows that the total amount of COD removed increases with the amount applied through the percent removal decreases. On the same graph if the points from high hydraulic loading are compared to those at low hydraulic loading, it can be seen that the removal of COD is greater at the low hydraulic loads. This is shown in another way (Figure 9) where the residence time is plotted

TABLE 10 - PERCENT REMOVALS @ 20°C

DATE	RBC UNIT	COD RBC WITH SECONDARY SETTLING	RBC UNIT	BOD RBC WITH SECONDARY SETTLING
Nov. 11	26	90.4	60	89.6
12	68	84.7	51	89.7
13	27	82.0		
14	11	83.7	32	86.4
15	10	77.3		
16		79.3		
17		72.8	17	85.1
18	36	87.7	39	89.3
19		88.5		
20	58	75.6	47	80.2
21	49	75.4		
22	22	55.9		
23	33	79.5		
24	41	76.5	69	87.9
25	23	72.4	53	84.9
26	23	72.5	23	78.7
27	46	79.4	55	82.6
28		68.5		
29	77	82.9		
30		70.4		
Dec. 1	50	64.7	75	87.3
2	50	79.7	61	85.4
3	59	80.9	70	85.6
4	40	80.9	63	93.2
5	28	44.0		
6	36	46.4		
7	5	34.2		
8	12	34.6		
9	20	22.0		
10				
11				
12	22	39.4	42	
13				
14	32	45.1		
15	12	39.0		
16	12	40.9		
17				
18	45	59.8	28	55.3
19		48.9	26	
20	48	59.1		
21		56.8		
22		90.3		

TABLE 10 - PERCENT REMOVALS @ 20°C

DATE	RBC UNIT	COD RBC WITH SECONDARY SETTLING	RBC UNIT	BOD RBC WITH SECONDARY SETTLING
Dec. 23	16	90.8		
24		86.2		
25		62.0		
26		54.6	50	92.5
27		85.6		
28		88.3		
29	61	89.8		
30	75	67.6		
31		86.9		
Jan. 1		63.8		
2	29	90.7	60	96.6
3	27	87.7		
4		94.3		
5		84.3		
6		67.7		
7	7	89.2		
8	72	90.8		
9	83	92.6	12	97.1
10	73	94.9		
11	41	95.7		
12		85.4		
13	31	87.6		
14	89	94.6		
15	82	86.1	89	91.1
16	60	81.2		
17		91.6		
18	48	82.8		
19				

PERCENT REMOVAL AVERAGES @ 20°C

FLOW	T.-°C	COD		BOD	
		RBC	SYSTEM	RBC	SYSTEM
40	18.1	16.3	83.3	43.7	88.1
80	17.5	32.7	74.8	55.1	83.3
240	16.2	21.5	43.9	31.8	45.7
40 - 15 rpm	13.3	0.0	80.7	55.7	94.6
40 *	13.2	42.1	91.2	93.9	97.6
80 *	14.4	70.5	87.2	87.9	90.4

* with Primary Clarifier

Figure 8.

EFFECT OF LOADING ON COD REMOVAL AT 20°C

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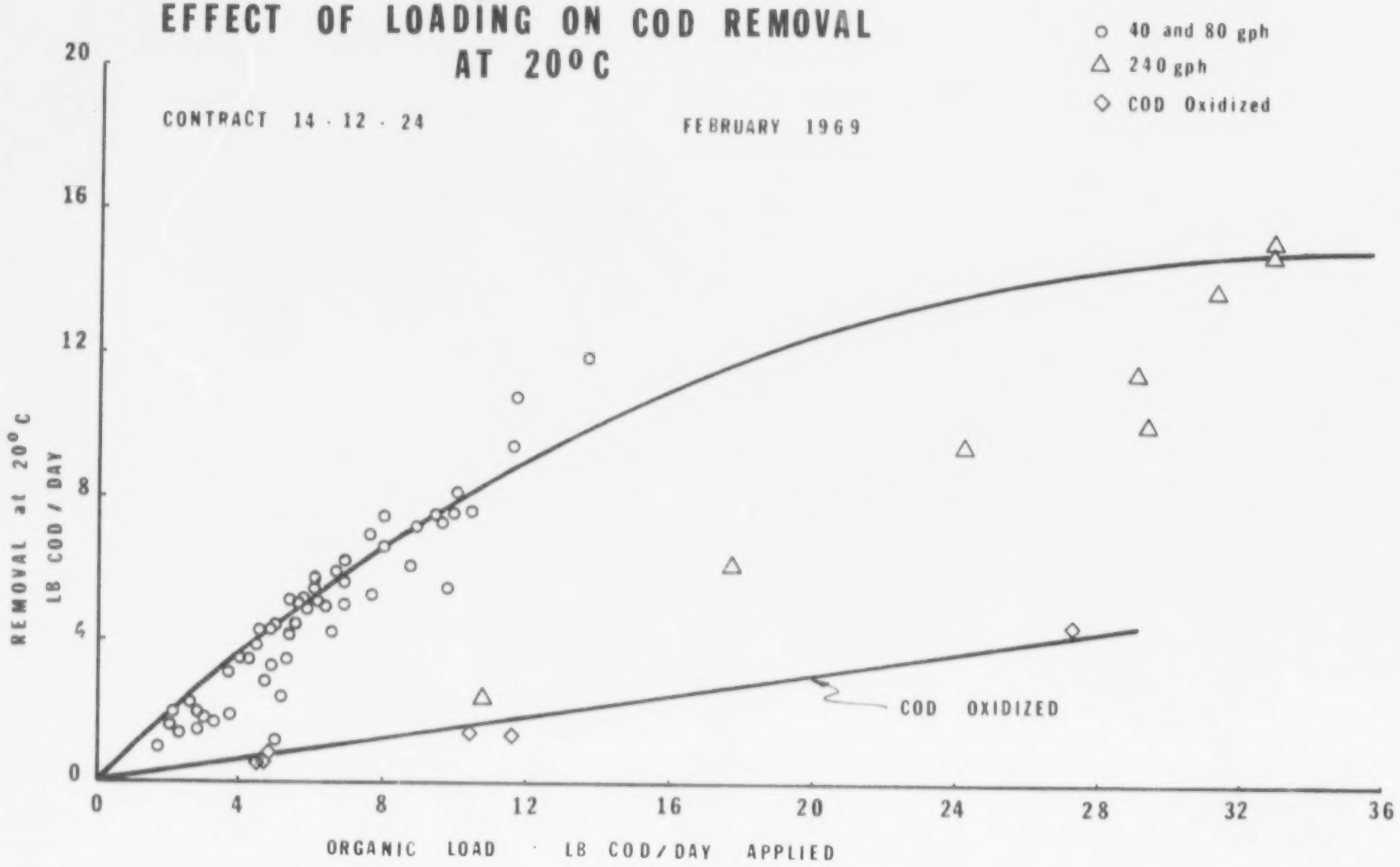

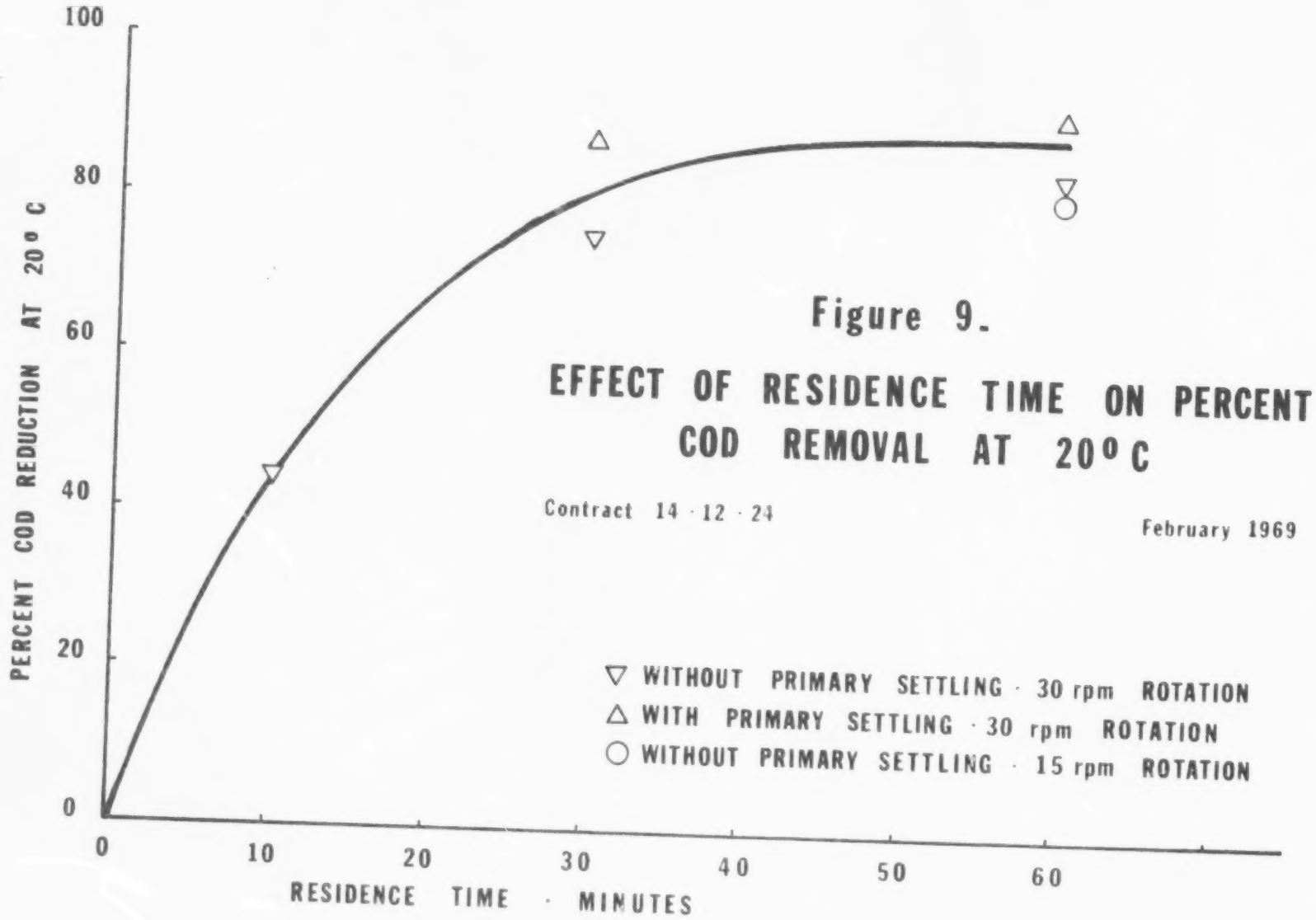

Figure 9.

EFFECT OF RESIDENCE TIME ON PERCENT COD REMOVAL AT 20° C

Contract 14 · 12 · 24

February 1969

against percent removal. At ten minutes residence time - high hydraulic loading - the efficiency of treatment is much lower than at the higher residence times. Figure 10 compares present results of residence time versus percent removal with the results from Phase I of this contract. It would indicate that the beginning of the curve may actually be steeper reaching an 80 percent removal at 30 minutes. The results from this phase do not contradict previous results but just fill in a part of the curve which was not measured before. Reduced contact time allows organic materials to pass through the unit with less probability of removal because of the lack of exposure to biological action.

Figure 8 also shows a plot of COD oxidized per pound of COD applied. It was assumed that the COD lost through the RBC unit was the total COD oxidized. Average COD removals through the RBC unit corrected to 20°C (from Table 10) were used for this line.

Figure 11 is another plot of pounds applied versus pounds removed. In this one three ranges of COD strength were selected and the points of these ranges were connected. For the low strength range - less than 350 mg/l COD, - there are not enough points in the higher hydraulic loadings - which are also higher organic loadings - to draw a curve through. The medium strength range and the high strength range follow similar patterns where there is a decreasing rate

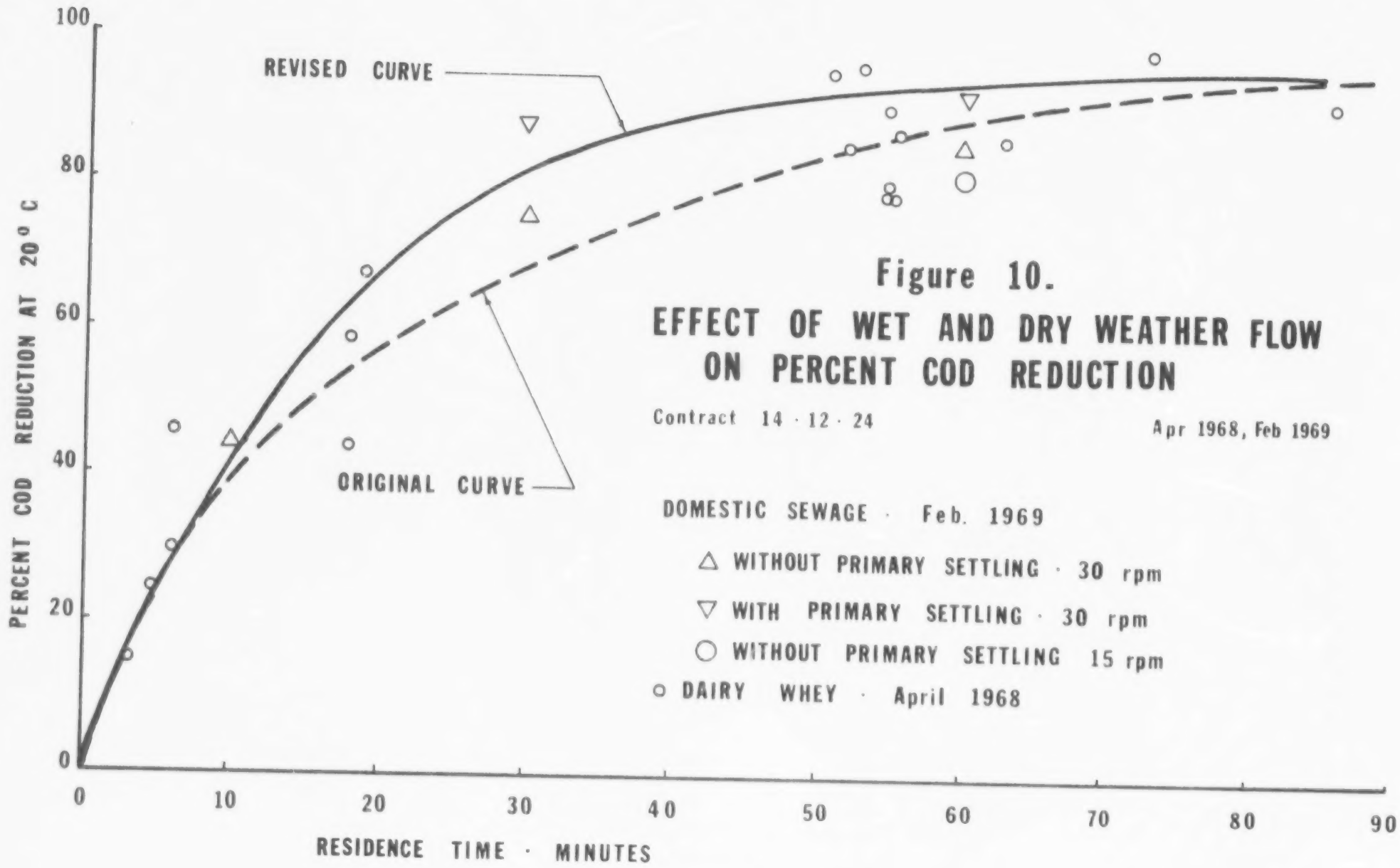

Figure 10.

EFFECT OF WET AND DRY WEATHER FLOW ON PERCENT COD REDUCTION

Contract 14 · 12 · 24

Apr 1968, Feb 1969

Figure 11.

EFFECT OF WASTE STRENGTH ON COD REMOVAL AT 20° C.

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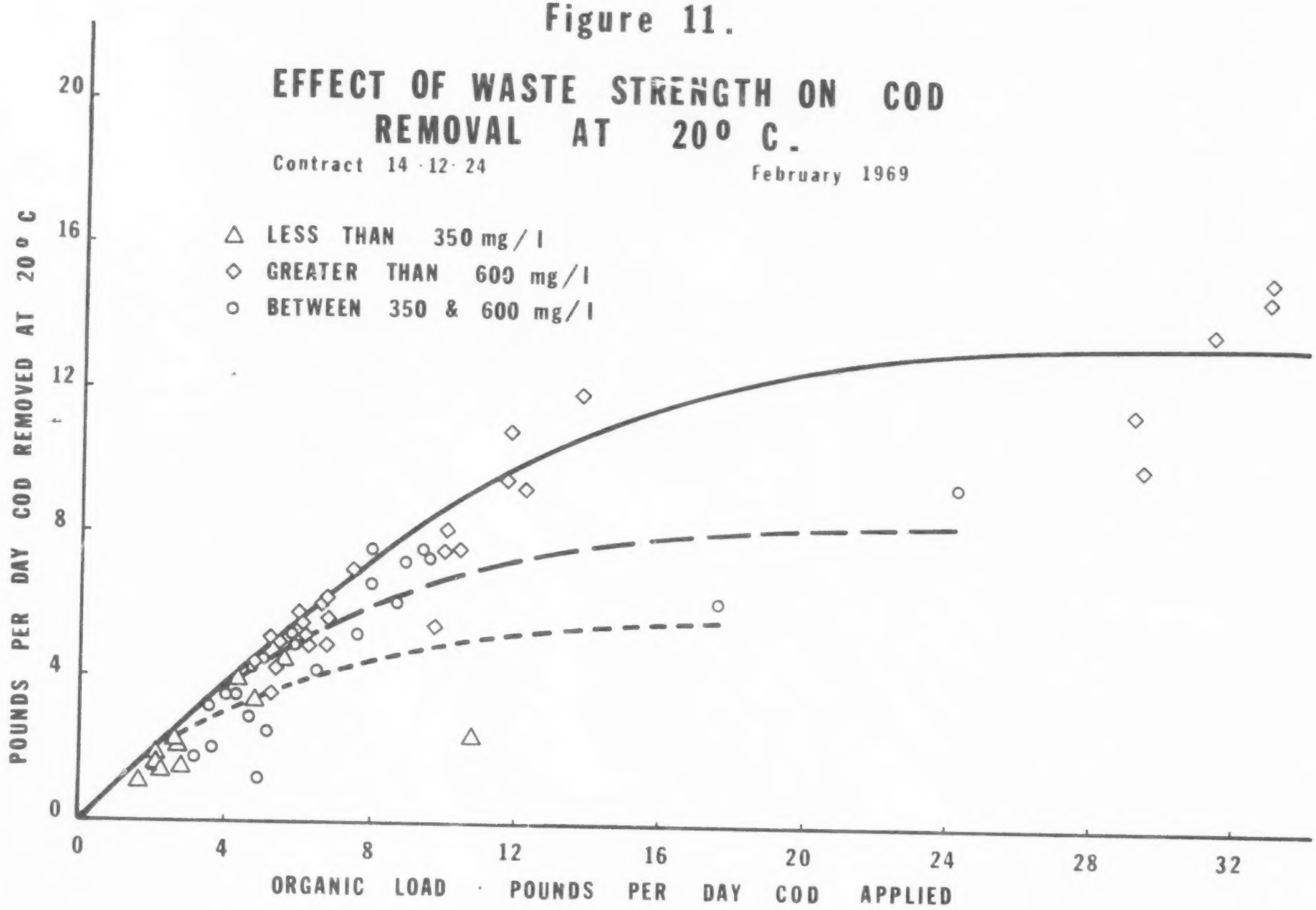


of COD removal.

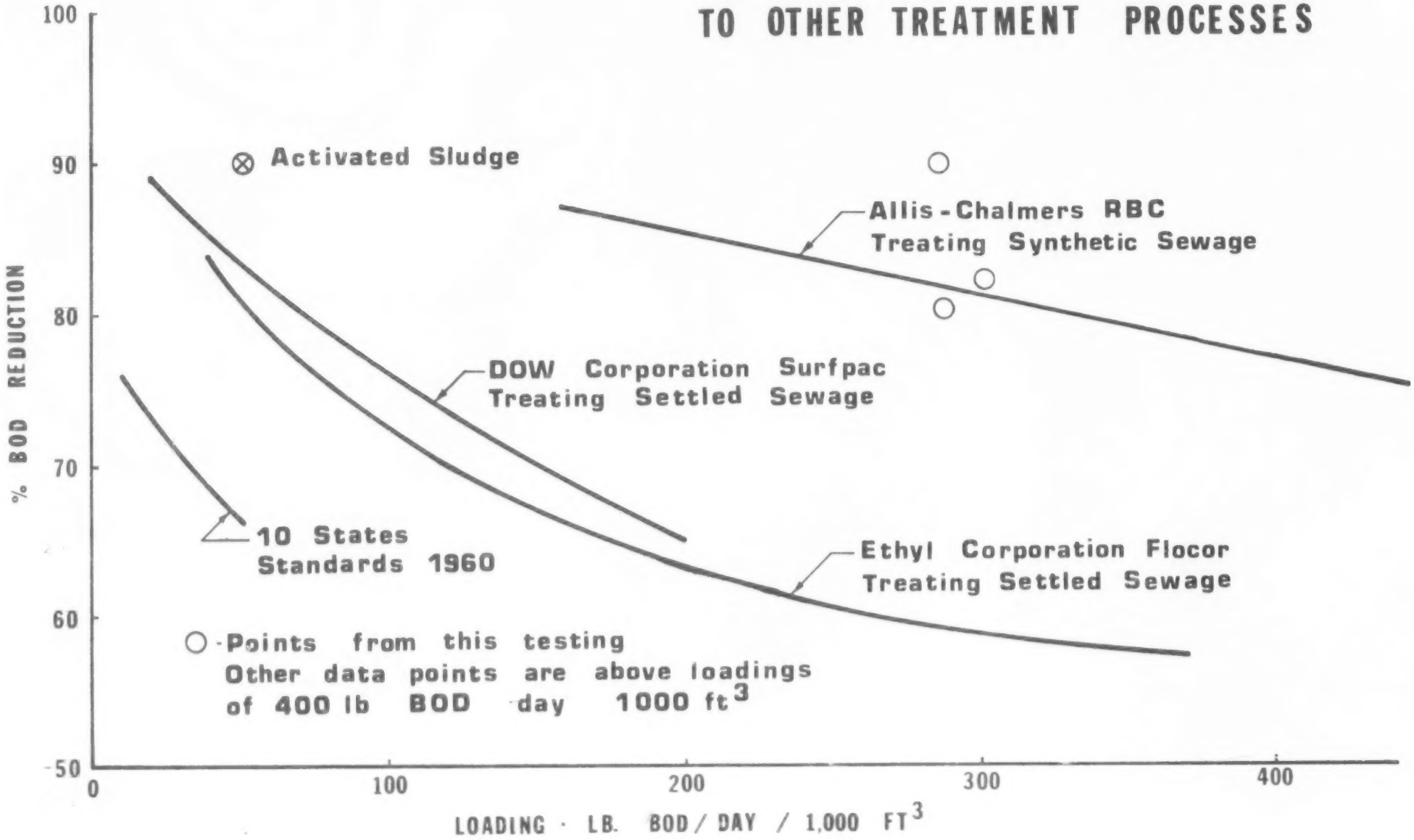
Figure 12 shows a comparison of the RBC performance to other treatment processes. The line for RBC performance is from previous testing. Points from Jones Island testing are shown. Other data points which are beyond the limits of the abscissa are not shown.

C. DISSOLVED OXYGEN

The dissolved oxygen of the raw sewage was usually low. When temperatures were very low the oxygen level of the sewage was higher because of the lower biological action in the sewage while flowing and the greater dissolved oxygen saturation level of the water. When the unit was run at 30 rpm the dissolved oxygen content of the effluent was always higher than the influent, and it came out at a level high enough for all demand for oxygen in the RBC unit by the microorganisms to be satisfied.

When the unit was run at 15 rpm the D.O. level of the effluent was sometimes lower than that of the influent. The D.O. sometimes was below the 1 mg/l which is considered to be the limiting level for sufficient oxygen to be available for microbiological action to proceed at its maximum rate in domestic sewage. So adequate aeration was not occurring at the 15 rpm rotation rate for the organic loadings being used.

Figure 12.
COMPARISON OF RBC PERFORMANCE TO OTHER TREATMENT PROCESSES



D. pH

Overall the pH at the effluent end averaged about .3 pH units below the influent pH. This may be attributed to the formation of some organic acids through the unit or to the use of ammonia by the microorganisms in the unit releasing hydrogen ions and lowering the pH. It is expected that the results are reasonably accurate because the meters were standardized each day. Loading conditions did not seem to affect pH much, but the lower rate of rotation may have had an effect. The pH out at 15 rpm averaged .66 units lower than the influent pH. If there was some anaerobic activity, which from the D.O. measurements there might have been, the formation of organic acids anaerobically would lower the pH.

E. SOLIDS AND TURBIDITY

The considerable reduction in turbidity through the unit at low flows indicates that the fine particles in the waste are flocculated - biologically or chemically - so the interference with the passage of light is reduced. At high flow the reduction in turbidity is minimal. This reading can give an indication of the reduction in suspended solids when a quick analysis of the performance of a unit is required.

Suspended Solids change through the RBC unit ranged from 80% removed to suspended solids increased. In the cases where solids increased through the unit it is probably

attributable to sloughing. Where very high removal occurred it is probable that it followed a period of sloughing and solids were being accumulated in the unit. The suspended solids reduction in the whole system ranged from 50.7 to 91.4 percent. The volatile suspended solids removal is in the same range. Not enough determinations were run to make a definite statement about the effect of hydraulic loading on suspended solids removal. But it would appear that, as with COD, an increased hydraulic load causes a loss in the performance of the unit.

Settleable solids analyses may give us an idea of the quantity of sludge produced through the unit and an approximate volume of sludge which would have to be handled. The solids concentration of the sludge was not determined. Samples may not have been entirely representative because of the variation in sloughing from day to day but overall the variations should average out. An average volume of sludge produced was determined by averaging the volumes of settleable solids. The lower flow rates seem to produce a greater volume of sludge per unit volume of waste flow though the total volume of sludge produced per day would be higher at higher flow rates. The low rate of disc rotation produced a lower volume of sludge, but the unit may have developed a heavy slime thus retaining most of the solids and washed off when the rate was increased without measurement of the result. The volumes of secondary sludge

produced ranged from 8.2 to 21.6 gallons/1000 gallons.

Use of settleable solids data and suspended solids data allow one to make an approximation of the solids content of the sludge. Using a 15 gallons per thousand gallons average sludge volume produced and a 230 pounds of solids settled per million pounds added gives a sludge with a solids concentration of 1.5%. Of course these are indirect results and an analysis of the sludge solids should be run to varify the numbers before any design is made based on the results. The volatile solids content of the sludge using averaged total suspended and volatile suspended solids removed is 74%.

F. BOD

The influent BOD averaged .64 of the influent COD. A plot of percent BOD removed versus percent COD removed (Figure 13) shows that the percent BOD removed averages about five percent more than the COD removed. This would be expected from the fact that the more easily biodegradable materials are removed rapidly in treatment while the less biodegradable and non-biodegradable materials remain and are measured in a COD analysis and not in a BOD analysis.

G. NITROGEN

Nitrite and nitrate in the RBC influent and effluent was generally insignificant indicating that no nitrification is

Figure 13.
RELATION OF BOD REMOVED TO COD REMOVED

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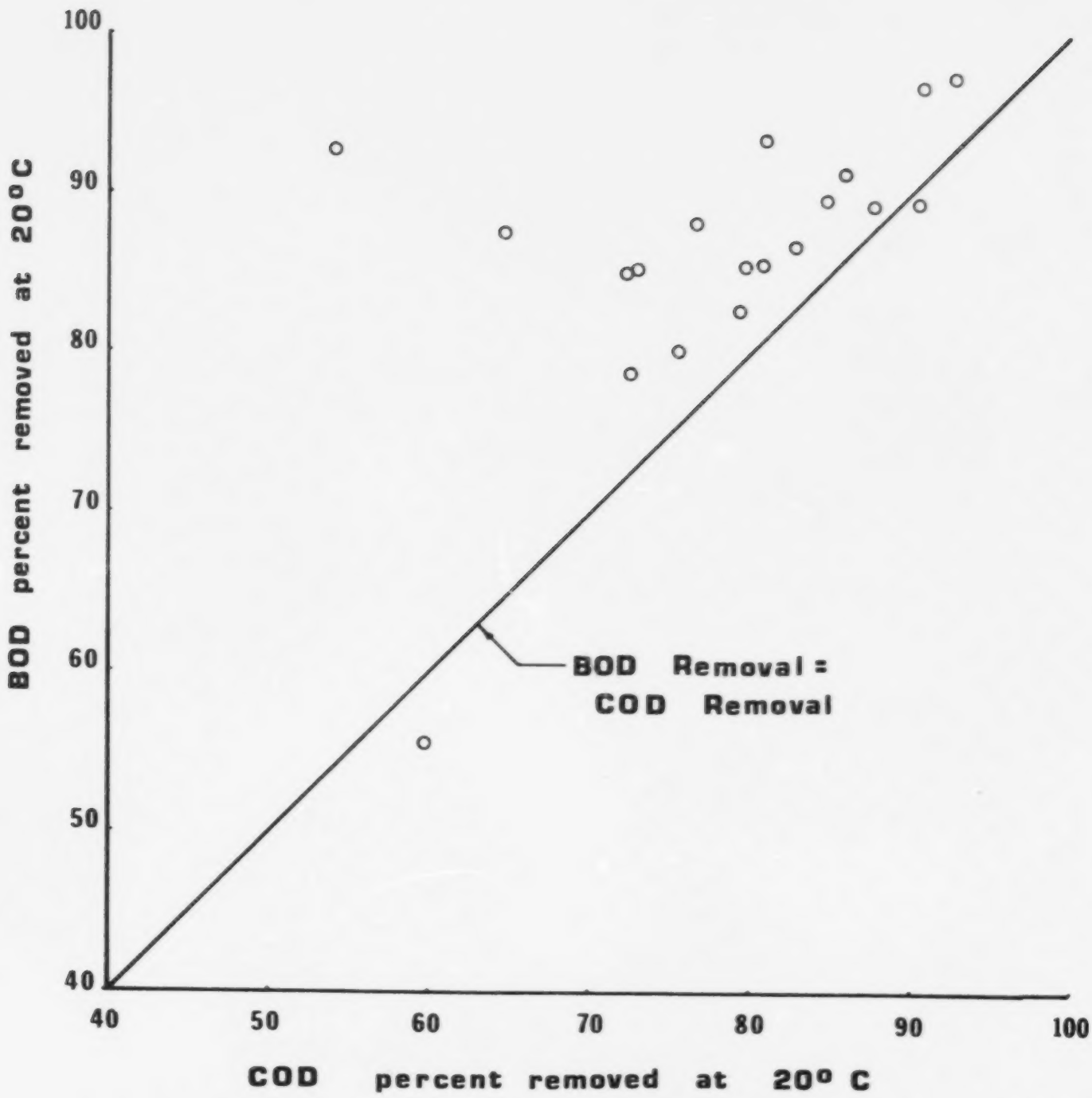

occurring. The discharge of ammonia and organic nitrogen places an oxygen demand on the receiving body of water. Discharge of nitrate in high concentrations along with phosphorus can cause algal problems in the receiving water. Ideally all of the nitrogen should be removed or it should not be discharged at a rate faster than it will be harvested from the water.

The pounds per day of Kjeldahl nitrogen removed versus pounds per day of COD removed (Figure 14) gives a ratio of about 25 to 1 of COD removed to nitrogen removed (15:1, BOD: N). Neither the COD nor nitrogen is corrected to 20°C. An average of 40.5 mg/l nitrogen was introduced to the unit while the clarifier effluent carried an average 24.7 mg/l. So an average 15.8 mg/l (37.7 percent) nitrogen was removed. If this is concentrated in the sludge produced at an assumed 15 gallons per thousand gallons (average value from the solids analysis) the nitrogen concentration in the sludge should be approximately 1200 mg/l.

The nitrogen in the influent was about 47 percent ammonia and 42 percent organic nitrogen. In the effluent the nitrogen is 65 percent ammonia and 35 percent organic indicating some of the complex molecules have been broken down through the RBC unit. The whole of the effluent nitrogen would have to be oxidized in a stream:

$$2NH_3 + \frac{9}{2} O_2 \quad 2 NO_3^- + 3H_2O$$

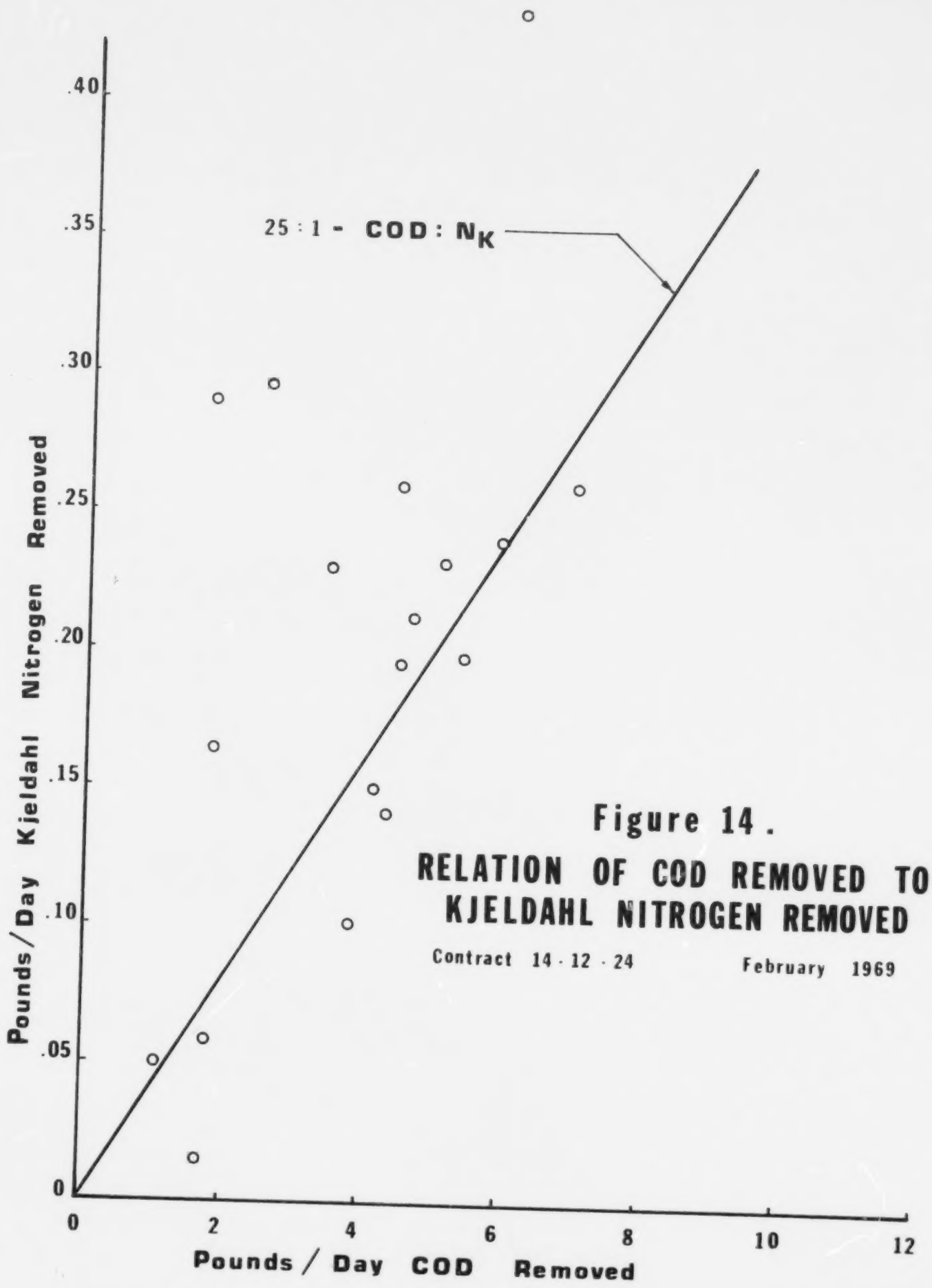

Figure 14.

RELATION OF COD REMOVED TO KJELDAHL NITROGEN REMOVED

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The conversion of ammonia to nitrate requires 4.57 parts oxygen to one part nitrogen. So the oxygen demand due to nitrogen is 24.6 x 4.57 or 113 mg/l nitrogenous oxygen demand. The RBC effluent is about twice as high in Kjeldahl nitrogen as the effluent from the Milwaukee Sewage Treatment Plant as published by the Milwaukee Sewerage Commission. The influent nitrogen concentration published is also 25% lower than the results analyzed here. At lower flow rates it is expected that removals in the RBC unit would compare more favorably with Metropolitan Sewerage Commission analyses.

H. PHOSPHORUS

The total phosphorus introduced to the RBC unit was about 8.5 mg/l half of which was dissolved phosphorus. Most of the dissolved phosphorus was orthophosphate. Through the RBC unit there was a decrease in dissolved phosphorus and orthophosphate due to the uptake of these forms by the microorganisms. Total phosphorus removal through the system averaged 53 percent. (Not corrected to 20°C) If the phosphorus removed is assumed concentrated in 15 gallons per thousand gallons of sludge the total phosphorus concentration in the sludge is about 300 mg/l.

The 4 mg/l phosphorus in the effluent would have to be removed if this were the only secondary treatment being used. Increased retention time in the unit would improve removal

but probably only by 1 mg/l, because the phosphorus available is in excess of the biological requirement.

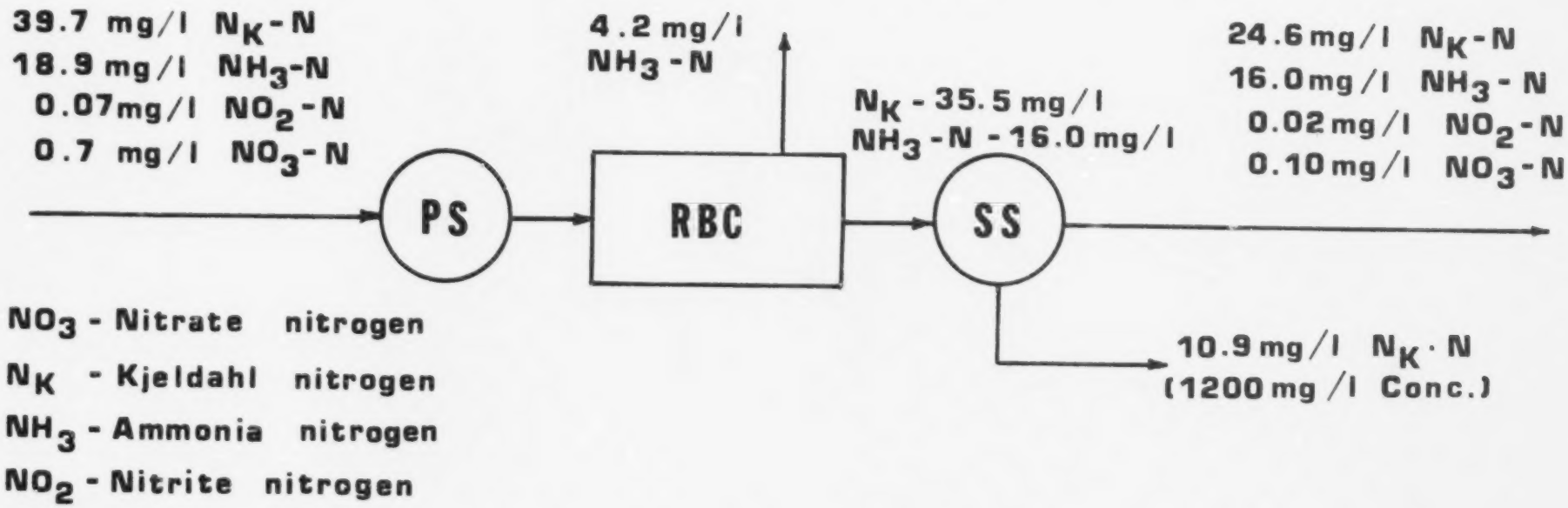
Figure 15 summarizes the distribution of nitrogen and phosphorus through the RBC system. Averages of all analyses are used, so the effluent concentrations represent also the values when high flow rates were used and poor treatment resulted.

I. PRIMARY CLARIFIER

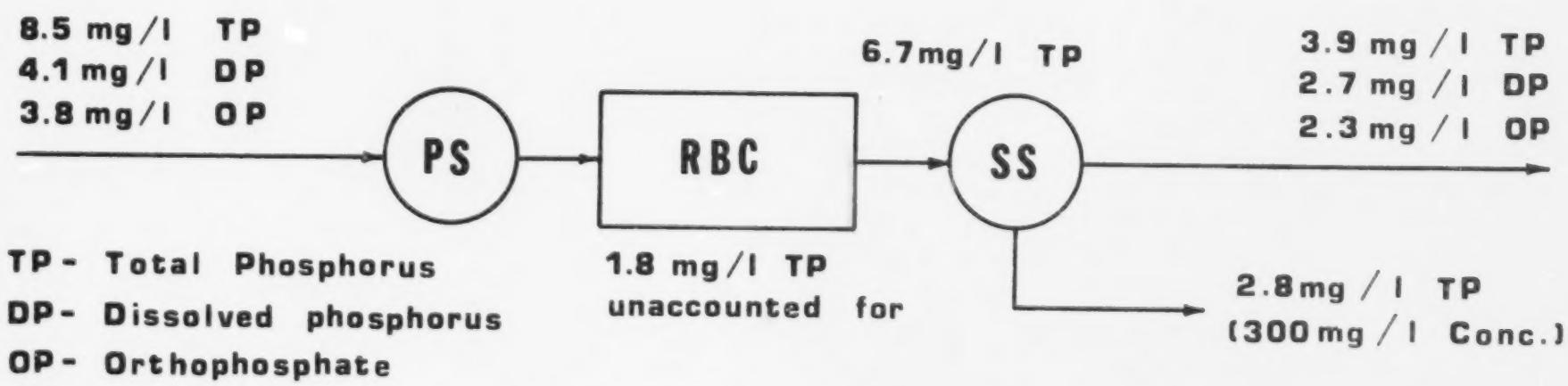
The primary clarifier removed settleable solids so it removed some of the suspended solids. It averaged 13% COD removal, but sometimes COD was decreased and sometimes increased through the clarifier. This may have been due to the fine screening step which had removed some of the settleable material. Not enough BOD, Nitrogen, and Phosphorus analyses were performed to draw any conclusions about their removal in the primary clarifier, but it would be expected that they would compare quite closely with the COD removal. The results of turbidity were comparable to the COD results. In other words when turbidity was higher out than in COD was also higher out than in.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. All parameters which were to be investigated for the FWPCA under this contract have been tested and the results analysed as called for. Conclusions which may be reached from



Nitrogen Distribution



Phosphorus Distribution

Figure 15.

analysis of the results follow.

The COD removal increases with COD applied. The COD oxidized also increases with the COD applied. The efficiency of treatment improves with increased retention time. Percent BOD removal is approximately 5% greater than percent COD removed. Ninety percent COD removal was attained at a loading of about 350 pounds per thousand cubic feet of disc volume per day. Nitrogen is removed in a ratio of 1:25, nitrogen to COD in the unit. Lower disc speed resulted in a slightly lower efficiency. Lower strength wastes cause a decrease in efficiency for the same organic loading. Recovery from increased hydraulic load is rapid.

B. As required in the FWPCA Contract 14-12-24 extension the following future activity is recommended.

1. From indirect data on the sludge the following analysis may be made:

Volume produced:	15 gal/1000 gal
Suspended Solids:	1.5%
Volatile Suspended Solids	1.1%
Phosphorus	300 mg/l
Nitrogen	1200 mg/l

Analyses should be made of the sludge to varify these values.

2. Analysis of the active biological organisms could be made for comparison to activated sludge and trickling filter organisms. Also for varying parameters the change in RBC organisms is of interest.

3. For effluent chlorination in secondary plants which may be constructed the chlorine demand of the RBC effluent should be determined.

4. Lower flow rates through an RBC unit should be used to determine the level of COD removal and nitrification which can be achieved.

5. Sludge should be recycled to determine the effect of the return organisms on the operation of the unit. Analysis of the waste sludge should be made to determine the degree of oxidation of the sludge because of recycle.

6. To attempt to improve nutrient removal Gro-Lux lamps could be installed over the RBC unit to encourage the growth of autotrophic algae.

7. Interstage settling may be installed to evaluate the effect on overall efficiency of treatment and quantity of sludge produced.

8. One section of the RBC unit could be used for sludge digestion as a means for determining the adaptability of the unit to use as an aerobic digestor.

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